1. Introduction:

The NSLS-II BEAMLINE RADIATION SHIELDING POLICY has been stated as follows in reference 1: Radiation exposure to staff and users resulting from National Synchrotron Light Source II (NSLS-II) operations must comply with Brookhaven National Laboratory (BNL) and Department of Energy (DOE) radiation requirements and must be maintained as low as reasonably achievable (ALARA). Per the NSLS-II Shielding Policy (PS-C-ASD-POL-005), in continuously occupied areas during normal operation the dose rate is ALARA, and shall be < 0.5 mrem/h (based on occupancy of 2000 hours/year) or less than 1 rem in a year.

For a fault event, the dose shall be < 20 mrem in a non-radiation controlled area and < 100 mrem in a radiation controlled area. Although the experimental floor is initially designated as a radiation controlled area, it is hoped that in the future, it can be declared a non-radiation controlled area. As such, beamlines should be shielded such that in the event of a fault, the total dose, integrated over the duration of the fault, is < 20 mrem.

Beamlines are required to shield against the two primary sources of radiation, the primary gas bremsstrahlung (GB) and the synchrotron radiation (SR), as well as the secondary radiation resulting from the scattering of these two primary beams by the beamline components and/or air. The shielding requirements for the First Optical Enclosure (FOE) are dominated by the scattering of the primary bremsstrahlung and not the synchrotron beam. Guidelines for the NSLS-II Beamline Radiation Shielding Design are also provided in reference 1. These guidelines were used to determine the thickness of the first optical enclosure (FOE) walls as well as dimensions of the supplementary shielding required to reduce the dose on the downstream FOE walls. The shielding recommended for the lateral and roof panels is generally sufficient for most white beam component configurations. However, the recommended as-built shielding for the downstream FOE wall may not be sufficient to protect against secondary gas bremsstrahlung (SGB) and additional shielding is usually necessary.

The radiation shielding analysis for the Flexible Access Macromolecular Crystallography (AMX) and Frontier Macromolecular Crystallography (FMX) beamlines (17ID-AMX/FMX) is documented in this technical note. The goal of the simulations documented here was to estimate the radiation dose levels generated inside and outside the FOE during normal operations and some fault conditions, thus evaluating the efficiency of the SGB shielding. The Fluka simulations were used to determine the position and dimensions of the SGB shielding. The simulations show that the SGB shields are needed to ensure that the dose rates outside the FOE are lower than 0.05 mrem/hr.

The layout of the 17ID-AMX-FMX beamlines is presented in figure 1. These drawings were extracted from the Beamline Ray Trace Layout [PD-AMX-FMX-RAYT-0001]. The ray trace drawings list the major components in the beamline and provide the position of each component.
Figure 1. The 17ID-AMX-FMX layout. The beam travels from right to left. The top figure is the plan view and the bottom figure the elevation view.

Since AMX and FMX are canted beamlines their layout is somewhat complex. The AMX white beam travels at an angle of 1.011 mrad with respect to the front end (FE) centerline and the FMX white beam travels at an angle of -0.989 mrad with respect to the FE centerline. The FE layout is shown in figure 2 was extracted from the Beamline Setup Table 6276-0001_NSLS-II_FMX-AMX-BLs_SetupTable_v30_2015-07-02_C. The positions of the major components were also extracted from the Beamline Setup Table.

Figure 2. The layout of the AMX and FMX beams with respect to the FE and short straight (SS) centerlines.

The NSLS-II primary gas bremsstrahlung (GB) source parameters are listed in Table 1.

Table 1. NSLS-II primary bremsstrahlung source parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy</td>
<td>3 GeV</td>
</tr>
<tr>
<td>Stored current</td>
<td>500 mA</td>
</tr>
<tr>
<td>Length of ID straight section</td>
<td>15.5 m</td>
</tr>
<tr>
<td>Pressure in straight section</td>
<td>1 ntorr</td>
</tr>
</tbody>
</table>

The beam is normalized at 17μW incident power, for the long (15.5m) straight. This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the straight sections is better than 10⁻⁹ Torr. The bremsstrahlung source file is attached as Appendix 2.
The Fluka model is described in section 2 and a sample Fluka input file is included in Appendix 3. The positions, dimensions, materials and drawings of the main components are included in Appendix 1. The following simulations were performed using these dimensions for the primary Gas Bremsstrahlung (GB) beam:

1. GB on AMX aperture of the dual aperture fixed mask
2. GB on FMX aperture of the dual aperture fixed mask
3. GB on AMX white beam slit 1
4. GB on AMX white beam slit 2
5. GB on AMX DCM crystal
6. GB on PPS mask upstream of Brem collimator 2
7. GB on FMX white beam slit 1
8. GB on FMX white beam slit 2
9. GB on silicon crystal
   
   **Simulations 1-9 performed with both SGB1 and SGB2 shields**

10. GB on AMX white beam slit 1 – SGB2 but no SGB1
11. GB on AMX white beam slit 2 – SGB2 but no SGB1
12. GB on FMX white beam slit 2 – SGB1 but no SGB2

The results of these simulations are described in section 3.

After the simulations had been finished the dual aperture SGB shield SGB2 was ordered to be built according to the specifications in Table 1.4 in Appendix 1. This lead shield was designed to have lateral dimensions 70 cm x 70 cm and a thickness of 5cm. The AMX and FMX apertures had a diameter of 10.0 cm. When the manufacturer’s drawings arrived it was noticed that the shielding near the two apertures did not have the full thickness. However outside a diameter of 12.0 cm the shield did have the specified thickness. This fact was modeled by increasing the diameters of the apertures from 10.0 to 12.0 cm. At the same time it was noted that dimensions of the guillotine were inverted. The guillotine should have been 84 cm wide and 80 cm high instead of 80 cm wide and 84 cm high. Neither of these factors was expected to increase the dose on the downstream wall significantly.

The results of simulations 1-9 had shown dose rates close to or larger than 0.05 mrem/h in only three cases. These three cases were re-done taking into account the larger values of the apertures in shield SGB2 and the changed dimensions of the guillotine. The results have been appended to the end of section 3 as sections 3.7-3.9. It was found that the dose on the downstream FOE wall did not change substantially in response to the two changes.

The results of the synchrotron radiation simulations are presented in section 4. Based on these calculation, the dose rates outside of the beam transport pipe and beamline enclosures are less than 0.05 mrem/hr on contact with the walls, roof and transport pipes.

A summary of all simulation results is presented in Section 5.
2. Description of the Fluka model

As recommended by reference 1 Appendix A we use the “custom GB generator based on an analytic representation of the source’s energy spectrum which was scaled in intensity in accordance with the experimental estimates of total GB power. This custom source assumes a $1/E$ energy spectrum dependency, with a maximum energy of 3GeV, and generates internally the corresponding probability density function from analytical descriptions”. The beam is normalized at $17 \mu W$ incident power, for the long (15.5m) straight. This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the straight sections is better than $10^{-9}$Torr.

Guidelines for the NSLS-II Beamline Radiation Shielding Design are also provided in reference 1. These guidelines were used to determine the thickness of the first optical enclosure (FOE) walls as well as dimensions of the supplementary shielding required to reduce the dose on the downstream FOE walls. The shielding recommended for the lateral and roof panels is sufficient for most white beam component configurations. However, the recommended as-built shielding for the downstream FOE wall may not be sufficient to protect against secondary gas bremsstrahlung (SGB) and additional shielding is usually necessary.

The 17ID-AMX-FMX Fluka model includes the FOE roof, sidewall, the downstream wall as well as the ratchet wall and long wall of the storage ring (SR). The FOE outboard lateral panel is made of 18 mm Pb (157 cm distance from beam), roof 10 mm Pb (200 cm above beam) and downstream FOE wall 50 mm Pb (~1904 cm from the ratchet wall).

The FLUKA geometry of the AMX-FMX beams is shown in figures 3(a) (Horizontal cut). For the Fluka models the Z axis represents the beam axis, the X axis the horizontal axis normal to the beam direction and the Y axis is the vertical axis. For the Ray Trace drawings the zero of the co-ordinate system is the center of the short straight. However, for the Fluka input files the downstream end of the ratchet wall is set as the zero of the Z axis.

![Figure 3(a). Horizontal cut of AMX/FMX FLUKA geometry at beam height](image)

In order to show some more detail the AMX components are shown in figure 3(b) and the FMX components in figure 3(c).
Figure 3(b). The positions of the dual aperture and AMX components.

Figure 3(c). The positions FMX and downstream components.

The positions, dimensions, materials and drawings of the main components are included in Appendix 1. The bremsstrahlung source file is attached as Appendix 2. A sample Fluka input file is included in Appendix 3.
3. Results for primary gas Bremsstrahlung (GB) simulations

At NSLS-II the white beam or First Optical Enclosure (FOE) shielding requirements are dominated by the scattering of the primary bremsstrahlung and not the synchrotron beam. The recommended shielding for lateral and roof panels is sufficient for most white beam component configurations. However, the recommended shielding for the downstream panels may not be sufficient to protect against secondary bremsstrahlung. In these cases, additional shielding against secondary bremsstrahlung for the downstream panel will be needed.

Simulations performed for [1] “show that significant amount of secondary (scattered) bremsstrahlung is created when the primary bremsstrahlung is incident on substantial white beam components. These white beam components primarily disperses the primary bremsstrahlung without significant energy loss; thereby greatly increasing the angular extent of very high-energy bremsstrahlung photons. Simulations show that it is necessary to intercept this secondary bremsstrahlung before they hit the downstream FOE wall.

3.1 GB on the AMX and FMX apertures of the dual aperture fixed mask

The Fluka image of the fixed mask is shown in figure 4. Both apertures are tapered in both x and y direction. In simulation 1 the GB impinges on the outboard tapered plane close to the neck of the AMX aperture. In simulation 2 the GB impinges on the outboard tapered plane close to the neck of the FMX aperture. Both SGB1 and SGB2 shields were included in the simulation.

![Figure 4. The dual aperture fixed mask with AMX and FMX apertures. The dual aperture Bremsstrahlung collimator 1 is immediately downstream of the FM.](image)

The total dose rate (mrem/h) distribution at the transverse beam plane (y=±4cm) is shown in figure 5 for the two cases. When the GB hits the AMX aperture the secondary GB travels down the AMX beam centerline. When the GB hits the FMX aperture the secondary GB travels down the FMX beam centerline. All components downstream of the GB starting position become SGB sources. In the AMX case additional shielding is provided by FMX components. Since some of the FMX components are relatively close to the FOE wall the dose on the FOE wall is higher in this case.
Figure 5. The total dose rate (mrem/h) distributions at the transverse beam plane (\(y=\pm 4\text{cm}\)) when GB impinges on the AMX aperture (top) and FMX aperture (bottom).

The dose distributions on the DS FOE wall are shown in figure 6 for the two cases. The maximum dose is much lower than the 0.05 mrem/h allowed by the NSLS-II shielding policy.

Figure 6. The dose distributions on the DS FOE wall: (a) GB incident on the AMX aperture and (b) GB incident on the FMX aperture.
The dose distributions on the roof and the sidewall look very similar for the two cases, therefore only the dose distributions for FMX aperture are presented in figure 7.

![Figure 7. The dose distributions on the FOE roof and sidewall when the GB impinges on the FMX aperture.](image)

In both cases the dose rate on the roof and the sidewall was less than 0.05 mrem/h.

3.2 GB on the AMX aperture of the dual aperture white beam slits S1 and S2 often called AMX slits 1 and 2.

In these simulations the GB was incident on the outboard plane of the AMX tapered aperture close to the neck. The beam still passed through approximately 3-4 cm of copper. Both SGB1 and SGB2 shields were included in the simulation. The dose distributions in the transverse plane and on the DS FOE wall for slit1 are shown in figure 8. The dose on the roof, sidewall and the DS FOE wall was found to be less than 0.05 mrem/h.

![Figure 8. The dose distributions in the transverse plane and on the DS FOE wall for AMX slit1.](image)

The dose distribution on the FOE wall for the AMX white beam slit 2 is shown in figure 9(a). The dose distribution 30 cm DS of the FOE wall is shown in figure 9(b).
The maximum dose on the DS FOE wall is ~0.1 mrem/h on contact but it reduces to less than 0.05 at 30 cm. The dose on the roof and the sidewall of the FOE was found to be less than 0.05 mrem/h.

3.3 GB on the AMX DCM silicon crystal 1
The dose distributions on the FOE wall and the transverse beam plane for the GB hitting the AMX DCM silicon crystal is shown in figures 10(a) and (b).

The GB is scattered by the Si crystal. However the gammas travelling in the forward direction are intercepted by the white beam stop, the bremsstrahlung stop and the SGB1 shield (see figure 2b) thereby drastically reducing the dose on the downstream FOE wall.

3.4 GB on the FMX PPS Mask
The positions of the FMX components are shown in figure 3(c). The PPS mask is immediately upstream of bremsstrahlung collimator 2. The GB impinges on the inboard tapered plane close to the neck of the FMX aperture. The dose distributions on the FOE wall and the transverse beam plane are shown in figures 11(a) and (b). The dose on the DS FOE
wall was found to be less than 0.02 mrem/h. The dose on the roof and the sidewall were found to be less than 0.05 mrem/h.

3.4 GB on the FMX white beam slits 1 and 2

The FMX white beam slits 1 and 2 are immediately downstream of bremsstrahlung collimator 2 (see figure 3(c). The apertures are tapered. The GB impinges on the outboard tapered plane close to the neck of the aperture. The position of the beam has some impact on the dose distribution on the FOE wall, the location of the maximum varies with the beam position. However, the maximum value of the dose does not change substantially. Dose rate distributions on the FOE DS wall, the roof and the sidewall are shown in figure 12.

The dose rate on contact with the wall is ~0.07 but the dose rate reduces to less than 0.05 at 30 cm from the wall. The position of the beam has some impact on the dose distribution on the FOE wall, the location of the maximum varies with the beam position. However, the maximum value of the dose does not change substantially.
Dose rate distributions on the FOE DS wall, the roof and the sidewall are shown in figure 13 when the GB beam is incident on the white beam slit 2.

For both cases (GB hitting slit 1 or slit 2) the maximum dose rate on contact on the FOE wall is higher than 0.05 mrem/h but decreases to below 0.05 mrem/h at 30 cm from the wall. The high-dose rate spots observed on the right of the AMX aperture are due to leakage through the AMX aperture in SGB2. Both the SGB2 shield and the guillotine are required to reduce the dose to acceptable levels on the FOE wall.

The dose rate distributions on the roof and sidewall are shown for slit 2 in figure 13(c) and (d). The maximum values of the dose rate on the roof and the sidewall of the FOE are lower than 0.05 mrem/h. The dose rate distributions and the maximum values of the dose are very similar for the case of GB on slit 1.

3.5 GB on the FMX DCM crystal 1
The positions of the FMX components including the FMX DCM are shown in figure 3(c). The DCM is immediately downstream of the white beam slit 2. The GB impinges on the front face of the outboard crystal. A narrow band of energies are reflected off the crystal but
most other photons are scattered or transmitted through the crystal. This scattered/transmitted beam is intercepted by the white beam stop, the Brem stop and the SGB2 shield. The dose distributions on the FOE wall and on the transverse beam plane are shown in figures 14(a) and (b).

![Dose distribution on FOE wall](image1)

![Dose distribution on transverse plane](image2)

**Figure 14.** The dose distributions in the transverse plane and on the DS FOE wall for GB impinging on DCM1

The maximum dose rate on contact on the FOE wall is lower than 0.01 mrem/h. The blue high-dose rate spot observed on the right of the AMX aperture is due to leakage through the AMX aperture in SGB2. The maximum values of the dose rates on the roof and the sidewall of the FOE were found to be lower than 0.05 mrem/h.

3.5 GB on AMX slits 1 and 2 without SGB1: simulations to show that SGB1 shield is required to reduce the dose on the downstream FOE wall.

These simulations were performed to check whether the SGB1 shield is required to reduce the dose on the downstream FOE wall. The dose rate distribution on the FOE DS wall (on contact) is shown in figure 15(a) for GB incident on AMX slit 1. The maximum value of the dose rate is approximately 0.06 mrem/h. However at 30 cm from the wall the dose rate reduces to less than 0.04 mrem/h (see figure 15(b)). This would lead to the conclusion that in this case the SGB1 shield may not be necessary.

![Dose distribution on FOE wall](image3)

![Dose distribution at 30cm](image4)

**Figure 15.** The dose rate distributions for GB impinging on AMX slit 1 on (a) the DS FOE wall and (b) 30 cm from the wall. Shield SGB1 was not included in this simulation.
The simulation was also done for GB incident on AMX slit 2 and again shield SGB 1 was removed. The dose rate distribution on the FOE DS wall (on contact) is shown in figure 16(a) for GB incident on AMX slit 2. The maximum value of the dose rate is > 0.2 mrem/h. At 30 cm from the wall the dose rate reduces to approximately 0.1 mrem/h (see figure 16(b)).

![Figure 16](image16.png)

**Figure 16.** The dose rate distributions for GB impinging on AMX slit 2 on (a) the DS FOE wall and (b) 30 cm from the wall. Shield SGB1 was not included in this simulation.

Since a dose rate of ~0.1 mrem/h is not acceptable according to the NSLS2 shielding policy the SGB1 shield is required to reduce the dose rate on the FOE wall.

### 3.6 GB on FMX slit 2 without SGB2: simulations to show that SGB2 shield is required to reduce the dose on the downstream FOE wall.

This simulation was performed to show that shield SGB2 is required to reduce the dose on the downstream FOE wall. Shield SGB1 was included in this simulation even though it has no impact on dose rates for GB incident on any of the FMX components. The simulation was identical to the one presented in section 3.4 except that SGB2 was effectively removed. The dose rate distribution on the FOE DS wall (on contact) is shown in figure 17(a) for GB incident on FMX slit 2. The maximum value of the dose rate is <0.3 mrem/h. At 30 cm from the wall the dose rate reduces to approximately 0.1 mrem/h (see figure 17(b)).

![Figure 17](image17.png)

**Figure 17.** The dose rate distributions for GB impinging on FMX slit 2 on (a) the DS FOE wall and (b) 30 cm from the wall. Shield SGB2 was not included in this simulation.
Since a dose rate of ~0.1 mrem/h is not acceptable according to the NSLS2 shielding policy it was decided that shield SGB2 is required to reduce the dose rate on the FOE wall.

The FLUKA simulations show that the secondary GB shields SGB1 and SGB2 are necessary to reduce the total dose rate to less than 0.05 mrem/hr at 30cm from the downstream wall of the FOE as required by NSLS-II shielding policy. The dose rates on the roof and the side wall of the FOE are always lower than 0.5 mrem/h.

3.7 GB on the AMX white beam slits 2: Diameter of both apertures in the dual-aperture shield SGB2 is increased from 10.0 to 12 cm, dimensions of guillotine modified

The total dose rates on the DS FOE wall are shown in figure 18(a) for dose on contact and 18(b) for dose at 30 cm from the wall. These dose rates should be compared with the dose rates in figure 9(a) and (b).

(a) Dose rate on contact with DS FOE wall

(b) Dose rate at 30 cm from DS FOE wall

Figure 18. The dose rate distributions on the DS FOE wall for GB on AMX slit2: (a) on contact with the wall, (b) at 30 cm DS of the wall.

The on-contact dose rate increased from ~0.10 to ~0.14 whereas the dose rate at 30 cm increased from 0.03 to 0.035 mrem/h. The dose distributions on the roof and the side wall of the FOE remain unchanged.

3.8 GB on the FMX aperture of the Fixed mask: Diameter of apertures in the dual-aperture shield SGB2 and dimensions of guillotine modified

The total dose rates on the DS FOE wall are shown in figure 19(a) for dose on contact and 19(b) for dose at 30 cm from the wall. These dose rates should be compared with the dose rates in figure 13(a) and (b). The high-dose rate spots observed on the right of the AMX aperture are due to leakage through the AMX aperture in SGB2. Both the SGB2 shield and the guillotine are required to reduce the dose to acceptable levels on the FOE wall.
3.9 GB on the FMX white beam slits 2: Diameter of both apertures in the dual-aperture shield SGB2 is increased from 10.0 to 12 cm, dimensions of guillotine modified

The total dose rates on the FOE downstream wall shown in figure 20 (a). These dose rates should be compared with the dose rate in figure 6(b). The dose rate distribution in the FOE is shown in figure 20(b). This is the vertical cut at the SS centerline, and shows higher dose rates above the guillotine. This is due to the fact that the GB was incident on the bottom plane of the aperture. If the GB had been lost on the top plane of the aperture the higher dose area would have been below the guillotine. The maximum dose rate on the FOE DS wall is approximately ~0.01 mrem/h, well below the allowed 0.05 limit.

The on-contact dose rate remains ~0.10 and the dose rate at 30 cm is still ~0.035 mrem/h. The dose distributions on the roof and the side wall of the FOE remain unchanged.
4. Synchrotron Radiation Calculation

The ID17 (AMX/FMX) beamline is an IVU21 source with its parameters given in Table 4.1 [2]. The horizontal opening angle for the 17ID source fan entering the first optics enclosure (FOE) is given in column 2. In addition, the NSLS-II stored electron beam parameters of 3 GeV and 500 mA (See Table 1) have been assumed to calculate the critical energy (column 6) and total integrated power (column 7).

Table 2: Source parameters used for 17ID (AMX/FMX) synchrotron calculations.

<table>
<thead>
<tr>
<th>Source</th>
<th>Max. source opening</th>
<th>No. Of periods</th>
<th>Max. $B_{eff}$ (T)</th>
<th>Period (mm)</th>
<th>$E_c$ (keV)</th>
<th>STAC 8 Total Power (kW) @ 500mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVU 21</td>
<td>1.0 mrad-H</td>
<td>74</td>
<td>0.921</td>
<td>21</td>
<td>5.5</td>
<td>3.9</td>
</tr>
</tbody>
</table>

The analytic code STAC8 [3] was used to calculate the ambient dose equivalent rates in the occupied areas outside beamline enclosures and transport pipes. The build-up factor in shield was included in the calculation. However, the effect of SR polarization was not considered leading to the same shielding requirements for the lateral wall and roof provided the distance from the scatter target to dose point is the same. The shielding calculations for the monochromatic beam pipe and experimental enclosures (17ID-B and 17ID-C) assumes that bremsstrahlung has been completely stopped in the FOE.

4.1 First Optics Enclosure (FOE)

The scattering target is assumed to be a silicon disk of 10 cm radius and 2 cm thick tilted at 0.155 degree with the respect to the incident beam [4]. The position of the scatter target is assumed to be located at FMX DCM approximately 450 cm from the FOE downstream wall, 158 cm from the lateral wall and 200 cm from the roof. The minimum required shielding for the SR source (no credit has been given to the SGB shielding or Guillotine) and the corresponding ambient dose rates are given in Table 3. The dose rate from SR is negligible on downstream wall, lateral wall, and roof with existing FOE shielding. The existing shielding thicknesses of the FOE walls and roof as given in Appendix 1 is more than adequate to meet the design requirement of 0.05 mrem/h.

Table 3: SR shielding design requirements for 17ID-A (FOE).

<table>
<thead>
<tr>
<th></th>
<th>Distance (cm)</th>
<th>Required Shielding</th>
<th>Ambient Dose rate (mrem/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral wall</td>
<td>158</td>
<td>4 mm Pb</td>
<td>0.0252</td>
</tr>
<tr>
<td>Roof</td>
<td>200</td>
<td>4 mm Pb</td>
<td>0.0158</td>
</tr>
<tr>
<td>Downstream Wall (&gt; 1°)</td>
<td>450</td>
<td>7 mm Pb</td>
<td>0.0173</td>
</tr>
</tbody>
</table>

4.2 Monochromatic Beam Transport Pipe

From the ray-tracing drawing (PD-AMX-FMX-RAYT-0001), the synchrotron max-fan for FMX when propagated through the monochromator (with HFM out of the beam) strike normal incidence the lead shielded junction box (used to transition from the 4” pipe to the 2” pipe) on its upstream face. This can be extrapolated from the ‘AMX/FMX MAX SYNCHROTRON, HORIZONTAL’ ray tracings given in Sheet 2 of PD-AMX-FMX-RAYT-0001. The relevant detail is shown in Figure 20. The drawings show that no portion
of this monochromatic max-fan can strike beam pipe walls. The max-fan is entirely stopped by the junction box faces that are perpendicular to the beam direction. There are the two layers of 5 mm lead sheeting that line the entire inner surface of the connector box for a total of 10 mm lead thickness in the direction of the fan. Additional shielding of about 10 mm provided by the two collars around the pipe has not been taken into account. Assuming five higher harmonic reflections (111, 333, 444, 555, and 777) of the fundamental mode of 22 keV with corresponding bandwidths [4, 5], the dose is calculated directly downstream of the junction box by the “NICK” card in STAC8. The calculated dose rate is 1.3E-03 mrem/hr which is below the design criteria of 0.05 mrem/hr.

Figure 21: Layout illustrating where FMX monochromatic beam strikes when HFM mirror is out of the beam. It shows that monochromatic beam from FMX DCM will strike the lead shielded junction box used to transition from the 4” pipe to the 2” pipe.

The FMX/AMX transport pipes are both 4” diameter stainless steel pipe wrapped by 5 mm lead (see Table 1.2). Both AMX and FMX have DCM following by mirror(s) to reflect the monochromatic beam to transport pipe and experimental enclosures (17ID-B and 17ID-C). The STAC8 calculation was carried using 10 m of air at one atmosphere as the potential scatterer inside the beam transport pipe, simulating a vacuum loss accident. The same beam harmonic energies and bandwidths discussed above have been used. The maximum dose rate on contact with the pipe is 5.3E-04 mrem/hr. With platinum coated mirror at 0.14 degree [2] to the incident beam, the dose rates are reduced by approximately a factor of 100.
4.3 End Station Enclosures (17ID-B and 17ID-C)

The side, downstream and roof panels of FMX/AMX enclosures are made of 6 mm Steel. Monochromatic beam stops have been installed on the downstream wall of the 17ID-B and 17ID-C enclosures to intercept a direct monochromatic and consist of 30 cm × 30 cm × 2.54 cm thick Pb. The minimum distance between the scattering targets and the walls is given in Table 4. The scattering target is assumed to be a 10 cm radius, 2 cm thick silicon disk, tilted at 0.155 degree to the incident beam located at 100 cm from the downstream wall. The calculation was carried out in STAC8 code using the same beam harmonic energies and bandwidths described above.

The dose rates on the lateral wall and roof are listed in Table 4. The dose rates for the downstream wall exceed 0.05 for scattering angles less than 20° reaching a dose rate of about 1.5 mrem/hr at 8°. However a reflecting mirror must be inserted to bring the monochromatic beam into the experimental enclosures and assuming platinum coated mirror at 2.5 mrad to the incident beam [2] the dose rates reduce to 0.026 mrem/hr on contact with the downstream wall without taking into account the monochromatic beam stop which cover scattering angles less than 8.5° for scattering target location of 100 cm.

<table>
<thead>
<tr>
<th>Table 4 Maximum dose rate on lateral wall and roof</th>
</tr>
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<tbody>
<tr>
<td>Distance (cm)</td>
</tr>
<tr>
<td>Lateral Wall</td>
</tr>
<tr>
<td>Roof</td>
</tr>
</tbody>
</table>
5. Summary and Conclusions

At NSLS-II the white beam or First Optical Enclosure (FOE) shielding requirements are dominated by the scattering of the primary bremsstrahlung and not the synchrotron beam. For the simulations the GB beam is normalized at 17μW incident power. This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the 15.5 m long straight sections is better than 10⁻⁹Torr. Based on the GB ray tracings for 17ID, beamline components that intercept the primary GB were selected as scattering targets in the simulations. A summary of the simulation results is presented in Table 5.

After the simulations had been finished the dual aperture SGB shield SGB2 was ordered to be built according to the specifications in Table 1.4 in Appendix 1. This lead shield was designed to have lateral dimensions 70 cm x 70 cm and a thickness of 5cm. The AMX and FMX apertures had a diameter of 10.0 cm. When the manufacturer’s drawings arrived it was noticed that the shielding near the two apertures did not have the full thickness. However outside a diameter of 12.0 cm the shield did have the specified thickness. This fact was modeled by increasing the diameters of the apertures from 10.0 to 12.0 cm. At the same time it was noted that dimensions of the guillotine were inverted. The guillotine should have been 84 cm wide and 80 cm high instead of 80 cm wide and 80 cm high. Neither of these factors was expected to increase the dose on the downstream wall significantly.

The results of simulations 1-9 had shown dose rates close to or larger than 0.05 mrem/h in only three cases. These three cases were re-done taking into account the larger values of the apertures in shield SGB2 and the changed dimensions of the guillotine. The results have been appended to the end of section 3 as sections 3.7-3.9. It was found that the dose on the downstream FOE wall did not change substantially in response to the two changes. The FLUKA simulations show that the secondary GB shields SGB1 and SGB2 are necessary to reduce the total dose rate to less than 0.05 mrem/hr at 30cm from the downstream wall of the FOE as required by NSLS-II shielding policy.

Based on the STAC8 calculation, the dose rates outside of the beam transport pipe and beamline enclosures are less than 0.05 mrem/hr on contact with the walls, roof and transport pipes.

All radiation shielding simulations should be validated by comparisons with measurements of the dose rates near the walls of the FOE, the beam transport pipe and the end station enclosure during commissioning.
Table 5. Maximum total dose rates (mrem/hr) on the roof, sidewall and downstream FOE wall on contact. The numbers in parentheses are the dose rates at 30 cm downstream of the FOE wall. Simulations 1-9 performed with both SGB1 and SGB2 shields.*Simulations with the larger values of the apertures in shield SGB2 and the changed dimensions of the guillotine.

<table>
<thead>
<tr>
<th>#</th>
<th>Simulation</th>
<th>Maximum dose (mrem/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Roof</td>
</tr>
<tr>
<td>1</td>
<td>GB on AMX aperture of the dual aperture fixed mask</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>2</td>
<td>GB on FMX aperture of the dual aperture fixed mask (FM)</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>*</td>
<td>GB on FMX aperture of the FM Modified SGB2 and Guillotine</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>3</td>
<td>GB on AMX/FMX white beam slit1 With SGB1 and SGB2</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>4</td>
<td>GB on AMX/FMX white beam slit2 With SGB1 and SGB2</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>*</td>
<td>GB on AMX/FMX white beam slit2 Modified SGB2 and Guillotine</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>5</td>
<td>GB on AMX DCM crystal 1</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>6</td>
<td>GB on PPS mask upstream of Brem collimator 2</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>7</td>
<td>GB on FMX white beam slit1 With SGB1 and SGB2</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>8</td>
<td>GB on FMX white beam slit2 SGB2 Aperture diameter 10.0 cm</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>*</td>
<td>GB on FMX white beam slit2 Modified SGB2 and Guillotine</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>9</td>
<td>GB on FMX DCM crystal 1</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>10</td>
<td>GB on AMX/FMX white beam slit1 With SGB2 no SGB1</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>11</td>
<td>GB on AMX/FMX white beam slit2 With SGB2 no SGB1</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>12</td>
<td>GB on FMX white beam slit2 With SGB1 no SGB2</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

6. References:

[2] Email from D. Schneider to M. Benmerrouche (December 29, 2015).
Appendix 1
Beamline Enclosures

Co-ordinate system
For non-canted beamlines the z axis lies along the long or short straight centerline. The positions (z co-ordinates) of the various components are defined with respect to the center of the straight. For canted beamlines like the AMX/FMX beamline the z axis can be placed along the short straight centerline or the front end (FE) centerline. The FE centerline is parallel to the short straight centerline but shifted outward along the x axis by $x_0 = 3.18$ mm (6276-0001-NSLS-II_FMX-AMX-BLs_SetupTable_v30_2015-0702-c.xls). The positions of the Front End components are defined with respect to the FE centerline whereas the positions of most of the components in the FOE are defined with respect to the short straight (SS) centerline.

The SS centerline was used as the z or beamline axis for the Fluka models. Y is the vertical axis and x the horizontal axis orthogonal to the y and z axes.

Table 1.1 Beamline Enclosures

<table>
<thead>
<tr>
<th>Wall</th>
<th>Position</th>
<th>Thickness</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/S End of 17-ID-A Ratchet Wall</td>
<td>2546.821 cm</td>
<td>5.0 cm</td>
<td>Lead</td>
</tr>
<tr>
<td>D/S End of FOE (17-ID-A) Backwall</td>
<td>4450.021 cm</td>
<td>1.8 cm</td>
<td>Lead</td>
</tr>
<tr>
<td>Distance of FOE Sidewall from SS CENTERLINE</td>
<td>158.0 cm</td>
<td>1.0 cm</td>
<td>Lead</td>
</tr>
<tr>
<td>Distance of FOE Roof from SS CENTERLINE</td>
<td>200.0 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance of FOE Floor from SS CENTERLINE</td>
<td>140.0 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U/S End of AMX hutch (17-ID-B) Wall</td>
<td>4650 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>D/S End of AMX hutch (17-ID-B) Wall</td>
<td>5400 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>Distance of AMX hutch outboard Sidewall from SS CENTERLINE</td>
<td>180.34 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>Distance of AMX hutch inboard Sidewall from SS CENTERLINE</td>
<td>167.64 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>Distance of AMX hutch Roof from SS CENTERLINE</td>
<td>200.0 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>U/S End of FMX hutch (17-ID-C) Wall</td>
<td>5400 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>D/S End of FMX hutch (17-ID-C) Wall</td>
<td>7100 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>Distance of FMX hutch outboard Sidewall from SS CENTERLINE</td>
<td>129.54 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>Distance of FMX hutch inboard Sidewall from SS CENTERLINE</td>
<td>165.10 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
<tr>
<td>Distance of FMX hutch Roof from SS CENTERLINE</td>
<td>200.0 cm</td>
<td>6mm</td>
<td>Steel</td>
</tr>
</tbody>
</table>
### Table 1.2 Beamline Transport Pipes:

<table>
<thead>
<tr>
<th>Description</th>
<th>ID</th>
<th>OD</th>
<th>Material</th>
<th>Shielding Thickness</th>
<th>Angle wrt Z axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Pipes between FOE &amp; SOE for the AMX beamline</td>
<td>3.888</td>
<td>4.00</td>
<td>Stainless Steel</td>
<td>5.0mm</td>
<td>0.86 °</td>
</tr>
<tr>
<td>Transport Pipes between FOE &amp; SOE for the FMX beamlines</td>
<td>3.888</td>
<td>4.00</td>
<td>Stainless Steel</td>
<td>5.0mm</td>
<td>-0.34 °</td>
</tr>
</tbody>
</table>

### Table 1.3 AMX/FMX Beamline Components and SGB shields.

<table>
<thead>
<tr>
<th>Components</th>
<th>Z = Distance from SS centerline</th>
<th>Dimensions (specify units)</th>
<th>Offset (vertical/horizontal w.r.t FE CENTERLINE &amp; Rotation)</th>
<th>Material</th>
<th>Associated Drawings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual Aperture AMX/FMX Fixed Mask DS of ratchet wall</td>
<td>2619.88 cm (U)</td>
<td>12cm (W), 10.6cm (H), 15.61cm (L)</td>
<td>Cu block centered wrt FE See fig 1.1 for aperture offsets</td>
<td>Glidcop (Copper)</td>
<td>C02a_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-Masks+Stops_Rev2.pdf</td>
</tr>
<tr>
<td>Bremsstrahlung Collimator 1 (Dual aperture)</td>
<td>US: 2641.88 cm</td>
<td>17.5 cm (W), 10.5cm (H), 30.48 cm (L)</td>
<td>Both apertures 1.2 cm (W), 1.2 cm (H)</td>
<td>Lead</td>
<td>C02b_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf</td>
</tr>
<tr>
<td>AMX/FMX White Beam Slits (H)</td>
<td>2737.98 cm</td>
<td>12cm (W), 10.6cm (H), 10.6 cm (L)</td>
<td>See fig 1.3 for details</td>
<td>Copper</td>
<td>C08a_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf</td>
</tr>
<tr>
<td>AMX/FMX White Beam Slits (V)</td>
<td>2771.58 cm</td>
<td>12cm (W), 10.6cm (H), 10.6 cm (L)</td>
<td>See figure 1.3 for details</td>
<td>Copper</td>
<td>C08a_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf</td>
</tr>
<tr>
<td>AMX DCM crystal 1</td>
<td>2862.182 cm</td>
<td>13.2cm (W), 5.9cm (H), 3.5cm (L)</td>
<td>Rotate 45 deg. wrt x axis DX:31mm DY:-1.75cm</td>
<td>silicon</td>
<td>C08a_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf</td>
</tr>
<tr>
<td>AMX DCM crystal 2</td>
<td>2862.182 cm</td>
<td>13.2cm (W), 5.9cm (H), 3.5cm (L)</td>
<td>Rotate 45 deg. wrt x axis DX:31mm DY:4.75cm</td>
<td>silicon</td>
<td>C08a_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf</td>
</tr>
<tr>
<td>AMX White Beam</td>
<td>2880.08 cm</td>
<td>Wedge:dx=4cm</td>
<td>Yoffset=-0.904in</td>
<td>copper</td>
<td>C08a_6276_NSLS-I1_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf</td>
</tr>
<tr>
<td>stop</td>
<td>(U)</td>
<td>y1=0.607 in</td>
<td>10mm X 10mm</td>
<td>Xoffset=1.252in Of SS centerline See fig 1.4(a)</td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-----</td>
<td>---------------</td>
<td>-------------</td>
<td>------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>AMX Bremsstrahlung Stop (W)</td>
<td>2888.18 cm (U)</td>
<td>9.2cm (W) 8.8cm (H) 20.5cm (L)</td>
<td>12.7cm aperture (diameter) centered wrt block</td>
<td>Offset Y=30mm X-Offset=1.144in Tungsten C02b_6276_NSLS-II_AMX+FMX-BlStechSpec-BSCollimators_Rev2.pdf</td>
<td></td>
</tr>
<tr>
<td>SGB01 shield</td>
<td>2929cm (U)</td>
<td>54.0 cm (x) 54.0 cm (y) 5 cm (z)</td>
<td>Y-Offset=3cm X-offset= 1.3 in rotated 3.5 mrad wrt y axis</td>
<td>lead</td>
<td></td>
</tr>
<tr>
<td>AMX TDM Mirror 1</td>
<td>3078.325 cm (C)</td>
<td>1cm x 1cm x 50cm</td>
<td>Centered on FMX centerline Offset = -3.5062 See figure 1.6(b)</td>
<td>Silicon</td>
<td></td>
</tr>
<tr>
<td>FMX PPS mask</td>
<td>3812.6 cm (U)</td>
<td>7.62 cm (x) 7.62 cm (y) 9.5 cm (z)</td>
<td>Asymmetric UP Aperture 4.065cm(x)2.483cm(y) DS: 0.85 x 0.85 cm</td>
<td>Centered on FMX centerline Offset = -3.5062 See figure 1.6(b)</td>
<td>GLIDcop (Copper) PPS-mask_0010_P94649_2187743.pdf</td>
</tr>
<tr>
<td>FMX Bremsstrahlung Collimator</td>
<td>3824.153 cm (U)</td>
<td>14.5 cm (x) 12cm (y) 30.48 cm (z)</td>
<td>1.6 cm (x) 1.6 cm (y) Centered wrt collimator block</td>
<td>Dx = -3.518 cm Lead C02b_6276_NSLS-II_AMX+FMX-BlStechSpec-BSCollimators_Rev2.pdf</td>
<td></td>
</tr>
<tr>
<td>FMX White Beam Slits (H)</td>
<td>3887.653 cm</td>
<td>7.6cm (x) 7.6 cm (y) 10.5cm (z)</td>
<td>UP 2.92cmx2.92cm DS: 1.1x1.1cm Z2=74.1mm Z1=29.4mm</td>
<td>DX=-3.59 cm Copper C08a_6276_NSLS-II_AMX+FMX-BlStechSpec-HighHeatLoadSlits_Rev4.pdf</td>
<td></td>
</tr>
<tr>
<td>FMX White Beam Slits (V)</td>
<td>3921.253 cm</td>
<td>7.6cm (x) 7.6 cm (y) 10.5cm (z)</td>
<td>UP 2.92cmx2.92cm DS: 1.1x 1.1cm Z2=74.1mm Z1=29.4mm</td>
<td>DX=-3.63 cm Copper C08a_6276_NSLS-II_AMX+FMX-BlStechSpec-HighHeatLoadSlits_Rev4.pdf</td>
<td></td>
</tr>
<tr>
<td>FMX DCM crystal 1</td>
<td>3991 cm</td>
<td>13.2cm (L) 5.9cm (W) 3.5cm (H)</td>
<td>45 degrees wrt Y axis inward DX=3.64 cm</td>
<td>silicon</td>
<td></td>
</tr>
<tr>
<td>FMX DCM crystal 2</td>
<td>3991 cm DX = FMX-3.0cm</td>
<td>13.2cm (L) 5.9cm (W) 3.5cm (H)</td>
<td>45 degrees wrt Y Face to face separation 3 cm DX=-6.64cm</td>
<td>silicon</td>
<td></td>
</tr>
<tr>
<td>FMX White Beam stop</td>
<td>US:4010.0 cm</td>
<td>Wedge: DX=4cm x1=0.607 in x2=1.2013 in</td>
<td>Xoffset = -6.704 Yoffset=0.0 of FMX centerline</td>
<td>copper</td>
<td></td>
</tr>
<tr>
<td>Shielding</td>
<td>Z = Distance from SS centerline U, D or C</td>
<td>Dimensions (specify units)</td>
<td>Offset (vertical or horizontal) Straight CENTERLINE</td>
<td>Material</td>
<td>Associated Drawings</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td>----------</td>
<td>---------------------</td>
</tr>
<tr>
<td>SGB1 shield</td>
<td>2929 cm (U)</td>
<td>Outer dimensions (W)x(H)x(L) 54.0 cm (x) 54.0 cm (y) 5 cm (z)</td>
<td>Offset Y = 30 mm Offset X=1.144in See fig 1.8</td>
<td>lead</td>
<td></td>
</tr>
<tr>
<td>New SGB2 shield</td>
<td>4125.0 cm (U)</td>
<td>Aperture (W)x(H) or (R) 12.7cm aperture (diameter) centered wrt block</td>
<td></td>
<td>Lead</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMX aperture diameter 10.0cm increased to 12.0 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FMX aperture diameter 10.0cm increased to 12.0 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.4. Beamline SGB Shielding**
Selected drawings for major components

Figure 1.1. Dual Aperture AMX/FMX Fixed Mask DS of ratchet wall

Ref C02a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-Masks+Stops_Rev2.pdf
Figure 1.2. Dual aperture Bremsstrahlung collimator 1
Ref: C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf
FMX: Rectangular aperture  
Offset = -2.465 cm  
25.2 mm x 25.2 mm  
AMX: Tapered aperture  
Offset: x = 3.054 cm  
US aperture 22.8 mm x 22.8 mm  
DS aperture 6 mm x 6 mm

Figure 1.3. Dual aperture Copper slits: FMX: Rectangular aperture AMX: Tapered aperture  
Reference: C08a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf
**Figure 1.4.** (a) AMX white beam stop (b) FMX white beam stop

**Figure 1.5.** (a) AMX and (b) FMX: Bremsstrahlung stops Ref : C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf
Figure 1.6. (a) Guillotine with AMX and FMX apertures (b) PPS mask for FMX. Beam goes from right to left. Note that the upstream aperture is asymmetric with respect to the FMX beam centerline.
Figure 1.7. (a) SGB1 is centered on the AMX beam centerline and (b) Dual aperture SGB 2 is centered on the SS centerline.
Appendix 2: Gas Bremsstrahlung Source File: src_bl2.f

*$ CREATE SOURCE.FOR
*COPY SOURCE
*
*== source ==================================================================
*
SUBROUTINE SOURCE ( NOMORE )

INCLUDE '(DBLPRC)'
INCLUDE '(DIMPAR)'
INCLUDE '(IOUNIT)'

*---------------------------------------------------------------* *

* Copyright (C) 1990-2010 by Alfredo Ferrari & Paola Sala
* All Rights Reserved.
* *
* New source for FLUKA9x-FLUKA20xy:
* *
* Created on 07 January 1990 by Alfredo Ferrari & Paola Sala
* Infn - Milan
* *
* Last change on 17-Oct-10 by Alfredo Ferrari
* *
* This is just an example of a possible user written source routine. *
* note that the beam card still has some meaning - in the scoring the *
* maximum momentum used in deciding the binning is taken from the *
* beam momentum. Other beam card parameters are obsolete.
* *
* Output variables:
* *
* Nomore = if > 0 the run will be terminated
INCLUDE '(BEAMCM)'
INCLUDE '(FHEAVY)'
INCLUDE '(FLKSTK)'
INCLUDE '(IOIOCM)'
INCLUDE '(LTCLCM)'
INCLUDE '(PAPROP)'
INCLUDE '(SOURCM)'
INCLUDE '(SUMCOU)'

LOGICAL LFIRST
*       SAVE LFIRST
DATA LFIRST / .TRUE. /

======================================================================
|                 BASIC VERSION                                        |
|                                                                      |
======================================================================

NOMORE = 0
* | First call initializations:
  IF ( LFIRST ) THEN
* | *** The following 3 cards are mandatory ***
  TKESUM = ZERZER
  LFIRST = .FALSE.
  LUSSRC = .TRUE.
* | *** User initialization ***
  GB_LO = WHASOU (1)
  GB_HI = WHASOU (2)
  IF (WHASOU(2) .LE. WHASOU(1) )STOP 'Emax <= Emin'
  WRITE(LUNOUT,*)
  WRITE(LUNOUT, '(A,132A)') ("*",I=1,132)
  WRITE(LUNOUT,*)"GB Low and high energy limits: GB_LO,GB_HI"
WRITE(LUNOUT,*)GB_LO,GB_HI
WRITE(LUNOUT,*)
*  +-------------------------------------------------------------------*
*  Push one source particle to the stack. Note that you could as well
*  push many but this way we reserve a maximum amount of space in the
*  stack for the secondaries to be generated
*  Npflka is the stack counter: of course any time source is called it
*  must be =0
NPFLKA = NPFLKA + 1
*  Wt is the weight of the particle
TKEFLK (NPFLKA) = GB_LO + (GB_HI -GB_LO) * FLRNDM(XDUMMY)
WTFLK (NPFLKA) = 1/TKEFLK(NPFLKA)
WEIPRI = WEIPRI + WTFLK(NPFLKA)
*  Particle type (1=proton.....). Ijbeam is the type set by the BEAM
*  card
*  +-------------------------------------------------------------------*
|  (Radioactive) isotope:
IF ( IJBEAM .EQ. -2 .AND. LRDBEA ) THEN
  IARES  = IPROA
  IZRES  = IPROZ
  IISRES = IPROM
  CALL STISBM ( IARES, IZRES, IISRES )
  IJHION = IPROZ * 1000 + IPROA
  IJHION = IJHION * 100 + KXHEAV
  IONID  = IJHION
  CALL DCDION ( IONID )
  CALL SETION ( IONID )
| |
| Heavy ion:
ELSE IF ( IJBEAM .EQ. -2 ) THEN
  IJHION = IPROZ * 1000 + IPROA
  IJHION = IJHION * 100 + KXHEAV
  IONID  = IJHION
CALL DCDION ( IONID )
CALL SETION ( IONID )
ILOFLK (NPFLKA) = IJHION
* | Flag this is prompt radiation
LRADDC (NPFLKA) = .FALSE.
* | Group number for "low" energy neutrons, set to 0 anyway
IGROUP (NPFLKA) = 0
* |
* +-------------------------------------------------------------------*
* | Normal hadron:
ELSE
   IONID = IJBEAM
   ILOFLK (NPFLKA) = IJBEAM
* | Flag this is prompt radiation
LRADDC (NPFLKA) = .FALSE.
* | Group number for "low" energy neutrons, set to 0 anyway
IGROUP (NPFLKA) = 0
END IF
* |
* +-------------------------------------------------------------------*
* From this point ..... 
* Particle generation (1 for primaries)
   LOFLK (NPFLKA) = 1
* User dependent flag:
   LOUSE (NPFLKA) = 0
* No channeling:
   LCHFLK (NPFLKA) = .FALSE.
   DCHFLK (NPFLKA) = ZERZER
* User dependent spare variables:
   DO 100 ISPR = 1, MKBMX1
      SPAREK (ISPR,NPFLKA) = ZERZER
100  CONTINUE
* User dependent spare flags:
   DO 200 ISPR = 1, MKBMX2
      ISPARK (ISPR,NPFLKA) = 0
200  CONTINUE
* Save the track number of the stack particle:
  ISPARK (MKBMX2,NPFLKA) = NPFLKA
  NPARMA = NPARMA + 1
  NUMPAR (NPFLKA) = NPARMA
  NEVENT (NPFLKA) = 0
  DFNEAR (NPFLKA) = +ZERZER
* ... to this point: don't change anything
* Particle age (s)
  AGESTK (NPFLKA) = +ZERZER
  AKNSHR (NPFLKA) = -TWOTWO
* Kinetic energy of the particle (GeV)
  TKEFLK (NPFLKA) = SQRT ( PBEAM**2 + AM (IONID)**2 ) - AM (IONID)
* Particle momentum
  PMOFLK (NPFLKA) = PBEAM
  PMOFLK (NPFLKA) = SQRT ( TKEFLK (NPFLKA) * ( TKEFLK (NPFLKA)
    & + TWOTWO * AM (IONID) ) )
* Cosines (tx,ty,tz)
  TXFLK (NPFLKA) = UBEAM
  TYFLK (NPFLKA) = VBEAM
  TZFLK (NPFLKA) = WBEAM
  TZFLK (NPFLKA) = SQRT ( ONEONE - TXFLK (NPFLKA)**2
    & - TYFLK (NPFLKA)**2 )
* Polarization cosines:
  TXPOL (NPFLKA) = -TWOTWO
  TYPOL (NPFLKA) = +ZERZER
  TZPOL (NPFLKA) = +ZERZER
* Particle coordinates
  XFLK (NPFLKA) = XBEAM
  YFLK (NPFLKA) = YBEAM
  ZFLK (NPFLKA) = ZBEAM
* Calculate the total kinetic energy of the primaries: don't change
  IF ( ILOFLK (NPFLKA) .EQ. -2 .OR. ILOFLK (NPFLKA) .GT. 100000 )
    & THEN
    TKESUM = TKESUM + TKEFLK (NPFLKA) * WTFLK (NPFLKA)
  ELSE IF ( ILOFLK (NPFLKA) .NE. 0 ) THEN
    TKESUM = TKESUM + ( TKEFLK (NPFLKA) + AMDISC (ILOFLK(NPFLKA)) )
&    * WTFLK (NPFLKA)
    ELSE
        TKESUM = TKESUM + TKEFLK (NPFLKA) * WTFLK (NPFLKA)
    END IF
    RADDLY (NPFLKA) = ZERZER
* Here we ask for the region number of the hitting point.
*     NREG (NPFLKA) = ...
* The following line makes the starting region search much more
* robust if particles are starting very close to a boundary:
    CALL GEOCRS ( TXFLK (NPFLKA), TYFLK (NPFLKA), TZFLK (NPFLKA) )
    CALL GEOREG ( XFLK  (NPFLKA), YFLK  (NPFLKA), ZFLK  (NPFLKA),
        &        NRGFLK(NPFLKA), IDISC )
* Do not change these cards:
    CALL GEOHSM ( NHSPNT (NPFLKA), 1, -11, MLATTC )
    NLATTC (NPFLKA) = MLATTC
    CMPATH (NPFLKA) = ZERZER
    CALL SOEVSV
    RETURN
*== End of subroutine Source =================================================================================
END
Appendix 3: Sample input file: 17ID-d5-FMXppsm.inp
In the input file SGB1 is referred to as SC01, SGB2 as SGB2.

TITLE
17ID-AMX-FMX Radiation Analysis
* Version History
* 10/23/2015: Modification of LIX-d5-fm to generate AMFMX-d1 (Vinita Ghosh)
* 11/16/2015: Changed angles of the transport pipes
* 11/30/2015: Version d4: Increased SGB01 to 54 x 54, SGB02 to 20 x 20, Guillotine apertures diameter = 3.888 inch, rotated the FMX WBS, added FMX PPS mask
* 12/02/2015: GB incident on FMX slit 2: FMX-d4-slit2.inp
* 12/03/2015: Corrections based on Mo's input
* 12/08/2015: Add Picture frame SGB3: Rerun slit 2: PF2 Decrease size of aperture, No SGB2
DEFAULTS
* Define the beam characteristics
BEAM           -3.0                 -.4                              PHOTON
* Define the beam position for FMX PPSM
BEAMPOS         -4.0       0.0    1273.0   -.0010013   0.0
* Define the beam position for AMX DCM crystal 1
*BEAMPOS         3.0       0.0     313.0 0.0010013       0.0
* Define the beam position for FM FMX aperture
*BEAMPOS        -2.0       0.0      83.0 0.0010013       0.0
* Define the beam position for AMX aperture
*BEAMPOS          3.2       0.0      83.0 0.0010013       0.0
* Define the beam position for AMX slit2
*BEAMPOS          3.4       0.0     230.0 0.0010013       0.0
* Define the beam position for AMX slit1
*BEAMPOS          3.4       0.0     197.0 0.0010013       0.0
* Define the beam position for FMX slit2
*BEAMPOS         -4.3       0.0    1379.0 -.0010013       0.0
* Define the beam position for FMX slit1
*BEAMPOS         -4.3       0.0    1344.0 -.0010013       0.0
* Define the beam position for test
*BEAMPOS         -3.5       0.0    1330.0 -.0010013       0.0
* Define the beam position for FMX dcml
*BEAMPOS         -3.5       0.0    1440.0 -.0010013       0.0
SOURCE           1E-5       3.0   0.00017
* Define the beam position for dcm (using horizontal max fan from Ray Tracings)
*BEAMPOS          1.5       0.0     590.0    0.0033       0.0
* Define the beam position for dcm (using vertical max fan from Ray Tracings)
*BEAMPOS          0.0    1.0778     590.0       0.0  0.001315
* Define the beam position for fixed mask
*BEAMPOS          0.3       0.0     99.0       0.0       0.0
* Define the beam position for white beam mirror
*BEAMPOS          0.0       0.0     220.0       0.0       0.0
* Define the beam position for wbs
*BEAMPOS          0.0       0.0     355.0       0.0       0.0
!@what.3=3.5*mrad
*ROT-DEFI        200.       0.0       0.035       0.0       0.0       0.0
*ROT-DEFI        200.       0.0       0.0       0.0       0.0      500.WBMrot
*ROT-DEFI        100.               -12.5                      -270.788
GEOBEGIN
  COMBNAME
    0 0
  * Black body
SPH blkbody      0.0 0.0 0.0 4000.0
  * Void sphere
SPH air          0.0 0.0 0.0 3000.0
#if 0
RCC Pipe        0.0 0.0 -2999.0 0.0 0.0 2999.0 1.0
#endif
  * Ratchet Wall simplified for ID beamlines
XYP rwxxA_i     -140.0
XYP rwxxA_o      0.0
YZP rwxxA_s     185.0
  * Sidewall simplified for ID beamlines
PLA swxxA_o     .99788010596582 0.0 0.0650791373456 -50.0 0.0 0.0
PLA swxxA_i     .99782149649341 0.0 0.06597166918965 -130.0 0.0 0.0
PLA swxxA_s     -.0407823695143 0.0 .99916805310057 -5.0 0.0 2000.0
  * SR Roof
XZP rfxxA_t    250.0
  * Distance of roof from centerline
XZP brfxxA_b  200.0
* Experimental floor 140 cm below centerline
XZP flxxA_b  -150.0
XZP flxxA_t  -140.0
* Beamline enclosure sidewall, roof and backwall
!@what.1=b(bswxxA_i,1)+1.8
YZP bswxxA_o  159.8
* Distance of sidewall from Straight Centerline
YZP bswxxA_i  158.0
* US of FOE downstream wall
!@what.1=4450.021-zro-5.0
XYP bbwxxA_i  1898.1999999999998
* Thickness of FOE DS wall 5cm
!@what.1=b(bbwxxA_i,1)+5.0
XYP bbwxxA_o  1903.1999999999998
!@what.1=b(brfxxA_b,1)+1.0
XZP brfxxA_t  201.
* US end of AMX hutch DS wall
!@what.1=(5400.0-zro)-5.0
XYP bfwwxB_o  2848.1790000000001
* DS end of AMX hutch DS wall
!@what.1=(5400.0-zro)
XYP bfwwxB_d  2853.1790000000001
* Front End beam pipe outer/outer shell, 2 mm thick beam SS pipe
!@what.3=-zro
!@what.6=zro
!@what.7=4.*inch/2.
RCC fep_o  0.0 0.0 -2546.8209999999999 0.0 0.0 2546.8209999999999
5.0800000000000001
!@what.3=-zro
!@what.6=zro
!@what.7=3.87*inch/2.
RCC fep_i  0.0 0.0 -2546.8209999999999 0.0 0.0 2546.8209999999999
4.9149000000000003
* AMX Beamline transport pipe inner shell: rotated 0.86 deg towards outboard side
!@what.7=3.888*inch/2.
RCC blp_i 23.77 3.0 1897.7 14.423591321394 0.0 960.87075012948
  4.9377599999999999
* AMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.7=4.000*inch/2.
RCC blp_o 23.77 3.0 1897.7 14.423591321394 0.0 960.87075012948
  5.0800000000000001
* AMX Beamline transport pipe shielding, 5 mm lead
!@what.7=b(blp_o,7)+0.5
RCC blp_shd 23.77 3.0 1897.7 14.423591321394 0.0 960.87075012948
  5.5800000000000001
#if 0
* AMX Beamline transport pipe inner shell: unrotated
!@what.1=23.77
!@what.2=3.0
!@what.3=b(bbwxxA_i,1)-0.5
!@what.6=b(bfwxxB_d,1) - b(bbwxxA_i,1)+5.0+1.0
!@what.7=3.888*inch/2.
RCC blp_i 23.77 3. 1897.69999999999998 0.0 0.0 960.97900000000027
  4.9377599999999999
#endif
#if 0
* AMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blp_i,1)
!@what.2=b(blp_i,2)
!@what.3=b(blp_i,3)
!@what.6=b(blp_i,6)
!@what.7=4.000*inch/2.
RCC blp_o 23.77 3. 1897.7 0.0 0.0 960.87075012948003 5.0800000000000001
#endif
#if 0
* AMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blp_i,1)
!@what.2=b(blp_i,2)
!@what.3=b(blp_i,3)
!@what.6=b(blp_i,6)
!@what.7=b(blp_o,7)+0.5
RCC blp_shd    23.77 3. 1897.7 0.0 0.0 960.87075012948003 5.5800000000000001
#endif
* FMX Beamline transport pipe inner shell: rotated 0.34 deg towards inboard side
!@what.7=3.888*inch/2.
RCC blpf_i    -8.296 0.0 1897.7 -11.2611240182 0.0 1897.6665875089
4.9377599999999999
* FMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.7=4.000*inch/2.
RCC blpf_o    -8.296 0.0 1897.7 -11.2611240182 0.0 1897.6665875089
5.0800000000000001 * FMX Beamline transport pipe shielding, 5 mm lead
!@what.7=b(blpf_o,7)+0.5
RCC blpf_shd   -8.296 0.0 1897.7 -11.2611240182 0.0 1897.6665875089
5.5800000000000001
#endif
#ifdef
* FMX Beamline transport pipe inner shell: unrotated
!@what.1=-8.296
!@what.2=0.0
!@what.3=b(bbwxxA_i,1)-0.5
!@what.6=b(bfwxxB_d,1) - b(bbwxxA_i,1)+5.0+1.0
!@what.7=3.888*inch/2.
RCC blpf_i    -8.2959999999999994 0.0 1897.6999999999998 0.0 0.0
960.979000000000027 4.9377599999999999
#endif
#ifdef
* FMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blpf_i,1)
!@what.2=b(blpf_i,2)
!@what.3=b(blpf_i,3)
!@what.6=b(blpf_i,6)
!@what.7=4.000*inch/2.
RCC blpf_o    -8.2959999999999994 0.0 1897.7 0.0 0.0 1897.6665875089
5.0800000000000001
#endif
#ifdef
* FMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blpf_i,1)
!@what.2=b(blpf_i,2)
!@what.3=b(blpf_i,3)
!@what.6=b(blpf_i,6)
!@what.7=b(blpf_o,7)+0.5
RCC blpf_sh -8.2959999999999994 0.0 1897.7 0.0 0.0 1897.6665875089
5.5800000000000001
#endif
* Fixed Mask: DS RW: AMX: copper block
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=(2619.88 - zro)
!@what.6=w(5)+15.61
RPP fm_af1 0.3180000000000006 6.3179999999999996 -5.2999999999999998
5.2999999999999998 73.059000000000196 88.669000000000196
* Fixed Mask: DS RW: FMX: copper block
!@what.1=xro -6.0
!@what.2=xro
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=(2619.88 - zro)
!@what.6=w(5)+15.61
RPP fm_af2 -5.6820000000000004 0.318 -5.2999999999999998 5.2999999999999998
73.059000000000196 88.669000000000196
* Fixed Mask: DS RW: small aperture block for AMX
!@what.1=2.925-0.35/2.
!@what.2=2.925+0.35/2.
!@what.3=-0.35/2.
!@what.4=0.35/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_in1 2.75 3.0999999999999996 -0.1749999999999999 0.1749999999999999
72.059000000000196 89.669000000000196
* Fixed Mask: DS RW: large aperture block for AMX
!@what.1=2.925-2.5/2.
!@what.2=2.925+2.5/2.
!@what.3=-2.5/2.
!@what.4=+2.5/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_ou1  1.6749999999999998 4.1749999999999998 -1.25 1.25 72.0590000000000196 89.6690000000000196
* Fixed Mask: DS RW: small aperture block for FMX
!@what.1=-2.338-0.35/2.
!@what.2=-2.338+0.35/2.
!@what.3=-0.35/2.
!@what.4=0.35/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_in2  -2.5129999999999999 -2.1630000000000003 -0.17499999999999999 0.17499999999999999 72.0590000000000196 89.6690000000000196
* Fixed Mask: DS RW: large aperture block for FMX
!@what.1=-2.338-2.5/2.
!@what.2=-2.338+2.5/2.
!@what.3=-2.5/2.
!@what.4=+2.5/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_ou2  -3.5880000000000001 -1.0880000000000003 -0.17499999999999999 0.17499999999999999 72.0590000000000196 89.6690000000000196
* Fixed Mask: DS RW: position of neck
!@what.1=b(fm_af1,6)-3.302
XYP fm_zc1  85.3670000000000189
* Fixed Mask: DS RW:
!@what.4=2.925+0.35/2.
!@what.6=b(fm_af1,6)-3.302
PLA fma_xo1  99.6208023 0.0 8.7003301 3.0999999999999996 0.0 85.3670000000000189
* Fixed Mask: DS RW:
!@what.4=-2.338+0.35/2.
!@what.6=b(fm_af1,6)-3.302
PLA fma_xo2  99.6208023 0.0 8.7003301 -2.1630000000000003 0.0
85.367000000000189

* Fixed Mask: DS RW:
!@what.1=b(fma_xo1,1)
!@what.2=b(fma_xo1,2)
!@what.3=-b(fma_xo1,3)
!@what.4=2.925-0.35/2.
!@what.5=b(fma_xo1,5)
!@what.6=b(fma_xo1,6)
PLA fma_xi1  99.620802299999994 0.0 -8.7003301000000004 2.75 0.0
85.367000000000189

* Fixed Mask: DS RW:
!@what.1=b(fma_xo2,1)
!@what.2=b(fma_xo2,2)
!@what.3=-b(fma_xo2,3)
!@what.4=-2.338-0.35/2.
!@what.5=b(fma_xo2,5)
!@what.6=b(fma_xo2,6)
PLA fma_xi2  99.620802299999994 0.0 -8.7003301000000004 -2.5129999999999999 0.0 85.367000000000189

* Fixed Mask: DS RW:
!@what.5=0.35/2.0
!@what.6=b(fm_af1,6)-3.302
PLA fma_yt1  0.0 99.6208023 8.7003301 0.0 0.17499999999999999               85.367000000000189

* Fixed Mask: DS RW:
!@what.1=b(fma_yt1,1)
!@what.2=b(fma_yt1,2)
!@what.3=-b(fma_yt1,3)
!@what.4=b(fma_yt1,4)
!@what.5=-b(fma_yt1,5)
!@what.6=b(fma_yt1,6)
PLA fma_yb1  0.0 99.620802299999994 -8.7003301000000004 0.0 -0.17499999999999999 85.367000000000189

* Bremsstrahlung Collimator dual aperture for both beams
!@what.1=xro -17.5/2.0
!@what.2=xro +17.5/2.0
*/

@what.3=-10.5/2.0
@what.4=-w(3)
@what.5=2641.88-zro
@what.6=w(5)+30.48
RPP brmcol
-8.4320000000000004 9.0679999999999996 -5.25 5.25
95.0590000000000196 125.5390000000002

* Bremsstrahlung Collimator aperture for AMX
@what.1=2.936-0.6
@what.2=w(1)+1.2
@what.5=2641.88-zro
@what.6=w(5)+30.48
RPP brmcolap
2.3359999999999999 3.5359999999999996 -0.60 0.6
95.0590000000000196 125.5390000000002

* Bremsstrahlung Collimator aperture for FMX
@what.1=-2.348-0.6
@what.2=w(1)+1.2
@what.5=2641.88-zro
@what.6=w(5)+30.48
RPP brmcolaf
-2.948 -1.748 -0.60 0.6 95.0590000000000196 125.5390000000002

* AMX White Beam Slit 1 block F
@what.1=xro -12.0/2.
@what.2=xro
@what.3=-10.6/2.
@what.4=-w(3)
@what.5=2737.98 - zro
@what.6=w(5)+10.6
RPP s1bf
-5.6820000000000004 0.318 -5.2999999999999998 5.2999999999999998
191.159000000000011 201.7590000000001

* AMX White Beam Slit 2 block F
@what.1=xro -12.0/2.
@what.2=xro
@what.3=-10.6/2.
@what.4=-w(3)
@what.5=2771.58 - zro
@what.6=w(5)+10.6
RPP s2bf
-5.6820000000000004 0.318 -5.2999999999999998 5.2999999999999998

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224.7590000000000000 235.3590000000000000
* AMX White Beam Slit 1 block F aperture
!@what.5=2737.98 - zro
!@what.6=w(5)+10.6
RPP s1bfap -3.725 -1.205 -1.26 1.26 191.15900000000001 201.75900000000001
* AMX White Beam Slit 2 block F aperture
!@what.1=s1bfapOS-2.52/2.
!@what.2=s1bfapOS+2.52/2.
!@what.3=-2.52/2.
!@what.4=-w(3)
!@what.5=2771.58 - zro
!@what.6=w(5)+10.6
RPP s2bfap -3.7249999999999996 -1.2049999999999998 -1.26 1.26               224.75900000000001 235.35900000000001
* AMX White Beam Slit 1 block A
!@what.1=xro
!@what.2=xro +12.0/2.
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=2737.98 - zro
!@what.6=w(5)+10.6
RPP slba 0.318 6.3179999999999996 -5.2999999999999998 5.2999999999999998               191.15900000000001 201.75900000000001
!@what.1=s1baapOS-0.6/2.
!@what.2=s1baapOS+0.6/2.
!@what.3=-0.6/2.
!@what.4=-w(3)
!@what.5=b(slba,5)-1.0
!@what.6=b(slba,6)+1.0
RPP slba_in 2.754 3.3539999999999996 -0.29999999999999999 0.29999999999999999               190.15900000000001 202.75900000000001
!@what.1=s1baapOS-2.28/2.
!@what.2=s1baapOS+2.28/2.
!@what.3=-2.28/2.
!@what.4=-w(3)
!@what.5=b(slba,5)-1.0
!@what.6=b(s1ba,6)+1.0
RPP s1ba_ou  1.9139999999999999 4.194 -1.1399999999999999 1.1399999999999999
       190.159000000000011 202.75900000000001
!@what.4=s1baapOS+0.6/2.
!@what.6=b(s1ba,6)-3.74
PLA s1ba_xo    99.2586389 0.0 12.1541190 3.3539999999999996 0.0
                198.019000000000009
!@what.1=b(s1ba_xo,1)
!@what.2=b(s1ba_xo,2)
!@what.3=-b(s1ba_xo,3)
!@what.4=s1baapOS-0.6/2.
!@what.5=b(s1ba_xo,5)
!@what.6=b(s1ba_xo,6)
PLA s1ba_xi    99.258638899999994 0.0 -12.154119 2.754 0.0 198.019000000000009
!@what.5=0.6/2.0
!@what.6=b(s1ba,6)-3.74
PLA s1ba_yt    0.0 99.2586389 12.1541190 0.0 0.29999999999999999
                198.019000000000009
!@what.1=b(s1ba_yt,1)
!@what.2=b(s1ba_yt,2)
!@what.3=-b(s1ba_yt,3)
!@what.4=b(s1ba_yt,4)
!@what.5=-b(s1ba_yt,5)
!@what.6=b(s1ba_yt,6)
PLA s1ba_yb    0.0 99.258638899999994 -12.154119 0.0 -0.29999999999999999
                198.019000000000009
!@what.1=b(s1ba,6)-3.74
XYP s1ba_zc    198.019000000000009
* AMX White Beam Slit 2 Block A
!@what.1=xro
!@what.2=xro +12.0/2.
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=2771.58 - zro
!@what.6=w(5)+10.6
RPP s2ba       0.318 6.3179999999999996 -5.2999999999999998 5.2999999999999998
224.75900000000001 235.35900000000001

!@what.1=s1baapOS-0.6/2.
!@what.2=s1baapOS+0.6/2.
!@what.3=-0.6/2.
!@what.4=-w(3)
!@what.5=b(s2ba,5)-1.0
!@what.6=b(s2ba,6)+1.0

RPP s2ba_in  2.754 3.3539999999999996 0.2999999999999999 -0.29999999999999999 0.29999999999999999

223.75900000000001 236.35900000000001

!@what.1=s1baapOS-2.28/2.
!@what.2=s1baapOS+2.28/2.
!@what.3=-2.28/2.
!@what.4=-w(3)
!@what.5=b(s2ba,5)-1.0
!@what.6=b(s2ba,6)+1.0

RPP s2ba_ou  1.9139999999999999 4.194 -1.1399999999999999 1.1399999999999999

223.75900000000001 236.35900000000001

!@what.4=s1baapOS+0.6/2.
!@what.6=b(s2ba,6)-3.74

PLA s2ba_xo  99.2586389 0.0 12.154119 3.3539999999999996 0.0 231.619

!@what.1=b(s2ba_xo,1)
!@what.2=b(s2ba_xo,2)
!@what.3=-b(s2ba_xo,3)
!@what.4=s1baapOS-0.6/2.
!@what.5=b(s2ba_xo,5)
!@what.6=b(s2ba_xo,6)

PLA s2ba_xi  99.258638899999994 0.0 -12.154119 2.754 0.0 231.619

!@what.5=0.6/2.0
!@what.6=b(s2ba,6)-3.74

PLA s2ba_yt  0.0 99.2586389 12.1541190 0.0 0.29999999999999999 231.619

!@what.1=b(s2ba_yt,1)
!@what.2=b(s2ba_yt,2)
!@what.3=-b(s2ba_yt,3)
!@what.4=b(s2ba_yt,4)
!@what.5=-b(s2ba_yt,5)
!@what.6=b(s2ba_yt,6)
PLA s2ba_yb   0.0 99.25863899999994 -12.154119 0.0 -0.29999999999999999 231.619
!@what.1=b(s2ba,6)-3.74
XYP s2ba_zc   231.619
#if 0
* AMX DCM crystal 1 not rotated
!@what.1=-5.9/2.
!@what.2=-w(1)
!@what.3=-3.5/2.+3.5
!@what.4=w(3)+3.5
!@what.5=-13.2/2.0
!@what.6=-w(5
RPP dcma1     -2.9500000000000002 2.9500000000000002 1.75 5.25
 -6.5999999999999996 0.0
#endif
* AMX DCM crystal 1 rotated 45 wrt x axis and translated z=2862.182-zro, y=-1.75, x=3.1cm
BOX dcma1     .15 -7.654341622908 311.93053211124 5.9 0.0 0.0 0.0 2.4748737341529 -2.474873734153 0.0 9.338095116624
 9.338095116624
#if 0
* AMX DCM crystal 2 not rotated
!@what.1=-5.9/2.
!@what.2=-w(1)
!@what.3=-3.5/2.+3.5
!@what.4=w(3)+3.5
!@what.5=-13.2/2.0
!@what.6=-w(5
RPP dcma2     -2.9500000000000002 2.9500000000000002 1.75 5.25
 -6.5999999999999996 0.0
#endif
* AMX DCM crystal 2 rotated 45 wrt x axis and translated z=2862.182-zro, y=4.75+1.5, x=3.1cm
BOX dcma2     .15 .345658377092 311.93053211124 5.9 0.0 0.0 0.0 2.4748737341529
 -2.474873734153 0.0 9.3338095116624 9.3338095116624
* AMX white beamstop US Z
!@what.1=2880.08-zro
XYP wbsta_zu  333.25900000000000
* AMX wbs DS Z
!@what.1=2880.08-zro+7.5
XYP wbsta_zd  340.75900000000000  
* AMX wbs xin
!@what.1=1.2521*inch-2.0
YZP wbsta_xi   1.1803340000000002  
* AMX wbs xout
!@what.1=1.2521*inch+2.0
YZP wbsta_xo   5.1803340000000002  
* AMX wbs Y bottom
!@what.1=-0.904*inch
XZP wbsta_yb   -2.29616  
#endif
* AMX wbs Y bottom
!@what.1=0.904*inch
XZP wbsta_yt   2.29616  
#endif
* AMX wbs Y top of wedge
!@what.4=1.2521*inch
!@what.5=1.2013*inch-0.904*inch
!@what.6=2880.08-zro+7.5
PLA wbsta_yt   0.0  98.034 -19.732 3.1803340000000002 0.7551420000000002  
340.75900000000000  
* AMX Brem Stop
!@what.1=-0.815
!@what.2=8.385
!@what.3=-3.80
!@what.4=5.0
!@what.5=2888.18-zro
!@what.6=w(5) + 20.5
RPP brms      -0.81499999999999995 8.3849999999999998 -3.7999999999999998 5. 
341.35899999999992 361.85899999999992  
* AMX Brem stop aperture
!@what.1=1.253*inch-1.0/2.  
!@what.2=w(1)+1.0
!@what.3=3.0-0.5
!@what.4=w(3)+1.0
!@what.5=b(brms,5)
!@what.6=w(5)+20.5
RPP brms_ap 2.6826199999999996 3.6826199999999996 2.5 3.5 341.35899999999992 361.85899999999992
  * SGB Shield SC01
!@what.1=-54.0/2.+sgb01xo
!@what.2=-w(1)+2.*sgb01xo
!@what.3=-54.0/2.+sgb01yo
!@what.4=-w(3)+2.*sgb01yo
!@what.5=2929.0-zro
!@what.6=w(5)+5.0
RPP sgb01 -24.094239999999999 29.905760000000001 -24. 30. 382.17900000000009 387.17900000000009
  * SC01 aperture
!@what.1=sgb01xo
!@what.2=sgb01yo
!@what.3=2929.0-zro
!@what.7=12.7/2.0
RCC sgb01_ap 2.9057599999999999 3. 382.17900000000009 0.0 0.0 5.0
6.3499999999999996
  * AMX TDM mirror 1 rotated
BOX tdm1 2.2143004616869 2.5 507.00590788775 .99999384658212 0.0
-0.035081046009 0.0 1.0 0.0 .17540523004399 0.0 49.999692329106
#if 0
  * AMX TDM mirror 1 unrotated
!@what.5=3078.325-zro-50./2.
!@what.6=w(5)+50.0
RPP tdm1 -0.5 0.5 -0.5 0.5 506.50399999999991 556.50399999999991
#endif
  * FMX PPS mask
!@what.1=ppsmos-7.62/2.
!@what.2=ppsmos+7.62/2.
!@what.3=-7.62/2.
!@what.4=-w(3)
!@what.5=3812.6 - zro
!@what.6=w(5)+9.5
RPP ppsmfmx -7.3162000000000003  0.3037999999999985 -3.8100000000000001
3.8100000000000001 1265.779 1275.279

* FMX PPS mask
!@what.1=ppsmos-0.85/2.
!@what.2=ppsmos+0.85/2.
!@what.3=-0.85/2.
!@what.4=-w(3)
!@what.5=b(ppsmfxm,5)-1.0
!@what.6=b(ppsmfxm,6)+1.0
RPP ppsm_in  -3.9312 -3.0812000000000004 -0.42499999999999999
0.42499999999999999 1264.779 1276.279

* FMX PPS mask
!@what.1=ppsmos-2.495
!@what.2=ppsmos+1.568
!@what.3=-2.483/2.
!@what.4=-w(3)
!@what.5=b(ppsmfxm,5)-1.0
!@what.6=b(ppsmfxm,6)+1.0
RPP ppsm_ou  -6.0012000000000008 -1.9382000000000001 -1.2415 1.2415 1264.779
1276.279

* FMX PPS mask
!@what.4=ppsmos+0.85/2.
!@what.6=b(ppsmfxm,6)-1.6
PLA ppsm_xo  98.9694848 0.0 14.3192558 -3.0812000000000004 0.0
1273.6790000000001

* FMX PPS mask
!@what.2=b(ppsm_xo,2)
!@what.3=-25.3468522
!@what.4=ppsmos-0.85/2.
!@what.5=b(ppsm_xo,5)
!@what.6=b(ppsm_xo,6)
PLA ppsm_xi  96.7343635 0.0 -25.3468522000000001 -3.9312 0.0 1273.6790000000001

* FMX PPS mask
!@what.4=ppsmos
!@what.5=0.85/2.0
!@what.6=b(ppsm_fmx,6)-1.6
PLA ppsm_yt 0.0 99.4701344 10.2806791 -3.5062000000000002 0.42499999999999999 1273.6790000000001
* FMX PPS mask
!@what.1=b(ppsm_yt,1)
!@what.2=b(ppsm_yt,2)
!@what.3=-b(ppsm_yt,3)
!@what.4=b(ppsm_yt,4)
!@what.5=-b(ppsm_yt,5)
!@what.6=b(ppsm_yt,6)
PLA ppsm_yb 0.0 99.470134400000006 -10.2806791 -3.5062000000000002 -0.42499999999999999 1273.6790000000001
* FMX PPS mask
!@what.1=b(ppsm_fmx,6)-1.6
XYP ppsm_zc 1273.6790000000001
* FMX Brem Collimator 2
!@what.1=brmcol2x-14.5/2.
!@what.2=brmcol2x+14.5/2.
!@what.3=-12.0/2.
!@what.4=-w(3)
!@what.5=3824.153-zro
!@what.6=w(5) + 30.48
RPP brmcol2 -10.768000000000001 3.7320000000000002 -6. 6. 1277.3319999999999 1307.8119999999999
* FMX Brem collimator aperture
!@what.1=brmcol2x-1.6/2.
!@what.2=brmcol2x+1.6/2.
!@what.3=-1.6/2.
!@what.4=-w(3)
!@what.5=b(brmcol2,5)
!@what.6=b(brmcol2,6)
RPP brmcol2a -4.3179999999999996 -2.718 -0.80000000000000004 0.80000000000000004 1277.3319999999999 1307.8119999999999
#if 0
* FMX Amy's copper target
!@what.1=s1fOS-2.54/2.
!@what.2=s1fOS+2.54/2.
!@what.3=-2.54/2.
!@what.4=-w(3)
!@what.5=3887.653 - zro -3.00
!@what.6=w(5)+2.54
RPP cutarg     -4.8599999999999994 -2.3199999999999998 -1.27 1.27
1337.8319999999999 1340.3719999999998 #endif
* FMX White Beam Slit 1
!@what.1=s1fOS-7.6/2.
!@what.2=s1fOS+7.6/2.
!@what.3=-7.6/2.
!@what.4=-w(3)
!@what.5=3887.653 - zro
!@what.6=w(5)+10.35
RPP s1fmx      -7.3899999999999997 0.20999999999999996 -3.7999999999999998               3.7999999999999998 1340.8319999999999 1351.1819999999998
!@what.1=s1fOS-1.1/2.
!@what.2=s1fOS+1.1/2.
!@what.3=-1.1/2.
!@what.4=-w(3)
!@what.5=b(s1fmx,5)-1.0
!@what.6=b(s1fmx,6)+1.0
RPP s1f_in     -4.1399999999999997 -3.04 -0.55000000000000004
0.55000000000000004 1339.8319999999999 1352.1819999999998
!@what.4=s1fOS+1.1/2.
!@what.6=b(s1fmx,6)-2.94
PLA s1f_xo     99.2546152 0.0 12.1869343 -3.04 0.0 1348.2419999999997
!@what.1=b(slf_xo,1)
!@what.2=b(slf_xo,2)
!@what.3=-b(slf_xo,3)
!@what.4=s1fOS-1.1/2.
!@what.5=b(slf_xo,5)
!@what.6=b(slf_xo,6)
PLA slf_xi 99.254615200000003 0.0 -12.186934300000001 -4.1399999999999997 0.0 1348.2419999999997
PLA slf_yt 0.0 99.2546152 12.1869343 0.0 0.55000000000000004 1348.2419999999997
PLA slf_yb 0.0 99.254615200000003 -12.186934300000001 0.0 -0.55000000000000004 1348.2419999999997
PLA slf_zc 1348.2419999999997
XYP slf_zc 1348.2419999999997
* FMX White Beam Slit 2
!@what.1=s2fOS-7.6/2.
!@what.2=s2fOS+7.6/2.
!@what.3=-7.6/2.
!@what.4=-w(3)
!@what.5=3921.253 - zro
!@what.6=w(5)+10.35
RPP s2fmx -7.429999999999997 0.16999999999999993 -3.799999999999998 3.799999999999998 1374.4320000000002 1384.7820000000002
!@what.1=s2fOS-1.1/2.
!@what.2=s2fOS+1.1/2.
!@what.3=-1.1/2.
!@what.4=-w(3)
!@what.5=b(s2fmx,5)-1.0
!@what.6=b(s2fmx,6)+1.0
RPP s2f_in      -4.1799999999999997 -3.0800000000000001 -0.55000000000000004
                     0.55000000000000004 1373.4320000000002 1385.7820000000002
!@what.1=s2fOS-2.92/2.
!@what.2=s2fOS+2.92/2.
!@what.3=-2.92/2.
!@what.4=-w(3)
!@what.5=b(s2fmx,5)-1.0
!@what.6=b(s2fmx,6)+1.0
RPP s2f_ou      -5.0899999999999999 -2.1699999999999999 -1.46 1.46               1373.4320000000002 1385.7820000000002
!@what.4=s2fOS+1.1/2.
!@what.6=b(s2fmx,6)-2.94
PLA s2f_xo     99.2546152 0.0 12.1869343 -3.0800000000000001 0.0
                   1381.8420000000001
!@what.1=b(s2f_xo,1)
!@what.2=b(s2f_xo,2)
!@what.3=-b(s2f_xo,3)
!@what.4=s2fOS-1.1/2.
!@what.5=b(s2f_xo,5)
!@what.6=b(s2f_xo,6)
PLA s2f_xi     99.254615200000003 0.0 -12.186934300000001 -4.1799999999999997
                  0.0 1381.8420000000001
!@what.5=1.1/2.0
!@what.6=b(s2fmx,6)-2.94
PLA s2f_yt     0.0 99.2546152 12.1869343 0.0 0.55000000000000004
                  1381.8420000000001
!@what.1=b(s2f_yt,1)
!@what.2=b(s2f_yt,2)
!@what.3=-b(s2f_yt,3)
!@what.4=b(s2f_yt,4)
!@what.5=-b(s2f_yt,5)
!@what.6=b(s2f_yt,6)
PLA s2f_yb     0.0 99.254615200000003 -12.186934300000001 0.0
                 -0.55000000000000004 1381.8420000000001
!@what.1=b(s2fmx,6)-2.94
XPY s2f_zc 1381.8420000000001
#if 0
* SGB Shield SC02
!@what.1=sgb02OS-20.0/2.
!@what.2=sgb02OS+20.0/2.
!@what.3=-20.0/2.
!@what.4=-w(3)
!@what.5=3946.0-zro
!@what.6=w(5)+5.0
RPP sgb02 -13.699999999999999 6.2999999999999998 -10. 10. 1399.1790000000001 1404.1790000000001
#endif
#if 0
* SC02 aperture
!@what.1=sgb02OS
!@what.3=b(sgb02,5)
!@what.7=5.0/2.
RCC sgb02_ap -3.7000000000000002 0.0 0.0 0.0 0.0 5.0 2.5
#endif
#if 0
* FMX DCM crystal 1 not rotated
!@what.1=-3.5/2.
!@what.2=-w(1)
!@what.3=-5.9/2.
!@what.4=-w(3)
!@what.5=-13.2/2.
!@what.6=-w(5)
RPP dcmf1 -1.75 1.75 -2.9500000000000002 2.9500000000000002 -6.5999999999999996 6.5999999999999996
#endif
* FMX DCM crystal 1 rotated 45 wrt y axis, translated z=1444.179, x=-1.89
BOX dcmf1 1.5394678887548 -2.95 1438.2746583771 2.4748737341529 0.0 2.4748737341529 0.0 5.9 0.0 -9.333809511662 0.0 9.3338095116624
#if 0
* FMX DCM crystal 2 not rotated
!@what.1=-3.5/2.

!@what.2=-w(1)
!@what.3=-5.9/2.
!@what.4=-w(3)
!@what.5=-13.2/2.
!@what.6=-w(5)
RPP dcmf2      -1.75 1.75 -2.9500000000000002 2.9500000000000002
              -6.5999999999999996 6.5999999999999996
# endif
* FMX DCM crystal 2 rotated 45 wrt y axis, translated z=1444.179, x=-8.39-1.5
BOX dcmf2     -6.460532111245 -2.95 1438.2746583771 2.4748737341529 0.0
              2.4748737341529 0.0 5.9 0.0 -9.333809511662 0.0 9.333809511662

* FMX wbs US Z
!@what.1=4010.0-zro
XYP wbstf_zu   1463.1790000000001

* FMX wbs_DS Z
!@what.1=b(wbstf_zu,1)+7.5
XYP wbstf_zd   1470.6790000000001

#if 0
* FMX wbs_xin
!@what.1=-3.6831 -3.0513+2.2962
YZP wbstf_xi   -4.4382000000000001
#endif

* FMX wbs xout
!@what.1=-3.6831+2.2962
YZP wbstf_xo   -1.3869000000000002

* FMX wbs Y bottom
!@what.1=-4.0/2.
XZP wbstf_yb   -2.
* FMX wbs Y bottom
!@what.1=4.0/2.
XZP wbstf_yt   2.
#if 0
* FMX wbs Y top of wedge
!@what.4=-6.704
!@what.5=1.2013*inch-0.904*inch
!@what.6=b(wbstf_zu,1)+7.5
PLA wbstf_yt  0.0 98.034 -19.732 -6.7039999999999997 0.7551420000000002 1470.6790000000001
#define
* FMX wbs inner surface of wedge
!@what.4=-3.6831+2.2962 -1.5418
!@what.6=b(wbstf_zu,1)
PLA wbstf_xi    98.0341143 0.0 19.7310016 -2.9287000000000001 0.0               1463.1790000000001
#if 0
* FMX wbs xin
!@what.1=-6.704-2.0
YZP wbstf_x1   -8.7040000000000006
#endif * FMX Brem Stop
!@what.1=-8.682
!@what.2=0.318
!@what.3=-4.0
!@what.4=4.0
!@what.5=4018.0-zro
!@what.6=w(5) + 20.5
RPP brmsfmx    -8.6820000000000004 0.318 -4. 4. 1471.1790000000001
1491.6790000000001
* FMX Brem Stop aperture
!@what.1=-7.182
!@what.2=-6.182
!@what.3=-1.0/2.
!@what.4=-w(3)
!@what.5=b(brmsfmx,5)
!@what.6=b(brmsfmx,6)
RPP brmsf_ap    -7.1820000000000004 -6.1820000000000004 -0.5 0.5 1471.1790000000001
1491.6790000000001
* SGB Shield SGB3:
!@what.1=-70.0/2.
!@what.2=-w(1)
!@what.3=-70.0/2.
!@what.4=-w(3)
RPP sgb3       -35. 35. 35. 35. 1578.1790000000001 1583.1790000000001
* SGB3 aperture - AMX beamline
!@what.1=sgb3xos+28.0
!@what.3=b(sgb3,5)
!@what.7=10.0/2.
RCC sgb3_apa   21.317999999999998 3.0 1578.1790000000001 0.0 0.0 5.0 5.
* SGB3 aperture - FMX beamline
!@what.1=sgb3xos
!@what.3=b(sgb3,5)
!@what.7=10.0/2.
RCC sgb3_apf   -6.6820000000000004 0.0 1578.1790000000001 0.0 0.0 5.0 5. #if 0
* SGB Shield SGB3: Picture frame
!@what.1=-60.0/2.
!@what.2=-w(1)
!@what.3=-64.0/2.
!@what.4=-w(3)
!@what.5=4315.0-zro
!@what.6=w(5)+5.0
RPP sgb3ap     -30. 30. -32. 32. 1768.1790000000001 1773.1790000000001
#endif
#if 0
* FMX HFM mirror 1  unrotated
!@what.1=hfm1OS-0.5
!@what.2=hfm1OS+0.5
!@what.5=4200.0-zro
!@what.6=w(5)+7.0
RPP hfm1       -7.3890000000000002 -6.3890000000000002 -0.5 0.5
1653.1790000000001 1660.1790000000001
* AMX Photon Shutter
!@what.1=pshOSx-12.5/2.
!@what.2=pshOSx+12.5/2.
!@what.3=-15./2.+pshOS
!@what.4=-w(3)+2.*pshOS
!@what.5=4390.0-zro
!@what.6=w(5)+3.8
RPP psh  17.0770000000000002  29.5770000000000002 -4.5  10.5
         1843.1790000000001  1846.979
* AMX Shutter aperture
!@what.1=pshOSx-4./2.
!@what.2=pshOSx+4./2.
!@what.3=-2.5/2.+pshOS
!@what.4=-w(3)+2.*pshOS
!@what.5=b(psh,5)
!@what.6=b(psh,6)
RPP psh_ap  21.3270000000000002  25.3270000000000002  1.75  4.25
         1843.1790000000001  1846.979
* FMX Photon Shutter
!@what.1=pshOSfmx-12.5/2.
!@what.2=pshOSfmx+12.5/2.
!@what.3=-15./2.
!@what.4=-w(3)
!@what.5=4348.2-zro
!@what.6=w(5)+3.8
RPP pshfmx  -14.1170000000000001  -1.617  -7.5  7.5  1801.3789999999999
         1805.1789999999999
* FMX Shutter aperture
!@what.1=pshOSfmx-4./2.
!@what.2=pshOSfmx+4./2.
!@what.3=-2.5/2.
!@what.4=-w(3)
!@what.5=b(pshfmx,5)
!@what.6=b(pshfmx,6)
RPP pshf_ap  -9.8670000000000009  -5.867  -1.25  1.25  1801.3789999999999
         1805.1789999999999
!@what.1=-80./2.
!@what.2=-w(1)
!@what.3=-84./2.+gioOS
!@what.4=-w(3)+2.*gioOS
!@what.5=4435.0-zro
!@what.6=w(5)+10.

RPP giotn      -40. 40. -42. 42. 1888.17900000000001 1898.17900000000001
* Guillotine aperture - AMX beamline
!@what.3=b(giotn,5)
!@what.7=3.888*inch/2.

RCC giotn_ap  23.774 3.0 1888.17900000000001 0.0 0.0 10.0 4.9377599999999999
* Guillotine aperture - FMX beamline
!@what.3=b(giotn,5)
!@what.7=3.888*inch/2.

RCC giotnfa   -8.296 0.0 1888.17900000000001 0.0 0.0 10.0 4.9377599999999999

END

* Black hole
BLKBODY      5 +blkbody -air

* Void around
AIR           5 +air +rwxxAi_i +rwxxA_s +swxxA_s -swxxA_i
               | +air +rwxxA_i +swxxA_s -rwxxA_s -swxxA_i
               | +air +rwxxA_i +rwxxA_s +swxxA_i +swxxA_s
               | +air +swxxA_s -rwxxA_i -rwxxA_s -swxxA_i
               | +air +rwxxA_s +swxxA_i +swxxA_s -rwxxA_i
               | +air -rwxxA_i -rwxxA_s -swxxA_i -swxxA_s
               | +air +rwxxA_s +bfwxxB_o -rwxxA_i -swxxA_i -swxxA_s -blp_shd -blpf_shd
               | +air +rwxxA_s +swxxA_i -rwxxA_s -swxxA_i
               | +air +rwxxA_s +swxxA_s -rwxxA_i -swxxA_i -rfxxA_t
               | +air +rwxxA_s +swxxA_s +flxxA_b -rwxxA_i -swxxA_i
               | +rwxxA_s +rfxxA_t +bbwxxA_o -rwxxA_o -flxxA_t -bswxxA_o
               | +rwxxA_s +swxxA_s +rfxxA_t -swxxA_o -flxxA_t -bbwxxA_o -blp_shd -blpf_shd
               | +rfxxA_t +bswxxA_o +bbwxxA_o -rwxxA_o -swxxA_o -brfxxA_t
               | +air -bfwxxB_o

* DS RW FM block1 AMX
FM_XXA        5 +fm_af1 -fma_in1 -fm_zcl
               | +fm_af1 +fm_zcl -fma_yt1

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| +fm_af1 +fma_yb1 +fm_zc1 |
| +fm_af1 +fma_yt1 +fm_zc1 -fma_xo1 -fma_yb1 |
| +fm_af1 +fma_xi1 +fma_yt1 +fm_zc1 -fma_yb1 |

* DS RW FM aperture 1 AMX
FMA_XXA 5 +fm_af1+fma_in1 -fm_zc1
| +fm_af1+fma_xo1 +fma_yt1 +fm_zc1 -fma_xi1 -fma_yb1 |

* DS RW FM block2 FMX
FM_XXF 5 +fm_af2 -fma_in2 -fm_zc1
| +fm_af2 +fm_zc1 -fma_yt1 |
| +fm_af2 +fma_yt1 +fm_zc1 -fma_xo2 -fma_yb1 |
| +fm_af2 +fma_xi2 +fma_yt1 +fm_zc1 -fma_yb1 |

* DS RW FM aperture 2 FMX
FMA_XXF 5 +fm_af2+fma_in2 -fm_zc1
| +fm_af2+fma_xo2 +fma_yt1 +fm_zc1 -fma_xi2 -fma_yb1 |

* Bremsstrahlung collimator
BRMCOL 5 +brmcol -brmcolap -brmcolaf
* Bremsstrahlung collimator aperture for AMX
BRMCOLAP 5 +brmcolap
* Bremsstrahlung collimator aperture for FMX
BRMCOLAF 5 +brmcolaf
* Slit 1 Block F
S1BF 5 +s1bf -s1bfap
* Slit 1 Block F aperture
S1BFAP 5 +s1bfap
* Slit 2 Block F
S2BF 5 +s2bf -s2bfap
* Slit 2 Block F aperture
S2BFAP 5 +s2bfap
* Slit 1 Block A
S1BA 5 +s1ba -s1ba_in -s1ba_zc
| +s1ba +s1ba_zc -s1ba_yt |
| +s1ba +s1ba_yb +s1ba_zc |
| +s1ba +s1ba_yt +s1ba_zc -s1ba_xo -s1ba_yb |
| +s1ba +s1ba_xi +s1ba_yt +s1ba_zc -s1ba_yb |

* AMX slit1 Block A aperture
S1BAAP  5 +s1ba +s1ba_in -s1ba_zc
    | +s1ba+s1ba_xo +s1ba_yt +s1ba_zc -s1ba_xi -s1ba_yb
* Slit 2 Block A
S2BA  5 +s2ba -s2ba_in -s2ba_zc
    | +s2ba +s2ba_zc -s2ba_yt
    | +s2ba +s2ba_yb +s2ba_zc
    | +s2ba +s2ba_yt +s2ba_zc -s2ba_xo -s2ba_yb
    | +s2ba +s2ba_xi +s2ba_yt +s2ba_zc -s2ba_yb
* AMX slit2 Block A aperture
S2BAAP  5 +s2ba +s2ba_in -s2ba_zc
    | +s2ba+s2ba_xo +s2ba_yt +s2ba_zc -s2ba_xi -s2ba_yb
* AMX DCM crystal 1
DCMA1  5 +dcma1
* AMX DCM crystal 2
DCMA2  5 +dcma2
* AMX white beamstop
AMXWBS  5 +wbsta_zd +wbsta_yt +wbsta_xo -wbsta_zu -wbsta_yb -wbsta_xi
* AMX Brem Stop
BRMSTP1  5 +brms -brms_ap
* Brem stop APERTURE
BRMSTPAP  5 +brms_ap
* SBS SC01
SC01  5 +sgb01 -sgb01_ap
* SBS SC01 aperture
SC01AP  5 +sgb01_ap
* AMX TD Mirror1
TDM1  5 +tdm1
* FMX PPS mask Cu block
PPSMFMX  5 +ppsmfmx -ppsm_in -ppsm_zc
    | +ppsmfmx +ppsm_zc -ppsm_yt
    | +ppsmfmx +ppsm_yb +ppsm_zc
    | +ppsmfmx +ppsm_yt +ppsm_zc -ppsm_xo -ppsm_yb
    | +ppsmfmx +ppsm_xi +ppsm_yt +ppsm_zc -ppsm_yb
* FMX PPS mask aperture
PPSMAP  5 +ppsmfmx +ppsm_in -ppsm_zc
    | +ppsmfmx+ppsm_xo +ppsm_yt +ppsm_zc -ppsm_xi -ppsm_yb
* Bremsstrahlubg collimator 2 for FMX
BRMCOL2 5 +brmcol2 -brmcol2a
* Bremsstrahlubg collimator aperture for FMX
BRMCOL2A 5 +brmcol2a
#if 0
* FMX Amy's copper target
CUTARG 5 +cutarg
#endif
* FMX white beam slit 1 Cu block
S1FMX 5 +s1fmx -s1f_in -s1f_zc
  | +s1fmx +s1f_zc -s1f_yt
  | +s1fmx +s1f_yb +s1f_zc
  | +s1fmx +s1f_yt +s1f_zc -s1f_xo -s1f_yb
  | +s1fmx +s1f_xi +s1f_yt +s1f_zc -s1f_yb
* FMX slit1 aperture
S1FMXAP 5 +s1fmx +s1f_in -s1f_zc
  | +s1fmx+s1f_xo +s1f_yt +s1f_zc -s1f_xi -s1f_yb
* FMX white beam slit 2 block
S2FMX 5 +s2fmx -s2f_in -s2f_zc
  | +s2fmx +s2f_zc -s2f_yt
  | +s2fmx +s2f_yb +s2f_zc
  | +s2fmx +s2f_yt +s2f_zc -s2f_xo -s2f_yb
  | +s2fmx +s2f_xi +s2f_yt +s2f_zc -s2f_yb
* FMX slit2 aperture
S2FMXAP 5 +s2fmx +s2f_in -s2f_zc
  | +s2fmx+s2f_xo +s2f_yt +s2f_zc -s2f_xi -s2f_yb
#if 0
* SBS SC02
SC02 5 +sgb02 -sgb02_ap
#endif
#if 0
* SBS SC02 aperture
SC02AP 5 +sgb02_ap
#endif
* SBS SGB02
SGB02 5 +sgb3 -sgb3_apa -sgb3_apf
* SBS SGB02 AMX aperture
SGB2_APA 5 +sgb3_apa
* SBS SGB02 FMX aperture
SGB2_APF 5 +sgb3_apf
#if 0
* SBS SGB3 Picture Frame
SGB3PF 5 +sgb3pf -sgb3ap
#endif
#if 0
* SBS SGB3 aperture
SGB3AP 5 +sgb3ap
#endif
* FMX DCM crystal 1
DCMF1 5 +dcmf1
* FMX DCM crystal 2
DCMF2 5 +dcmf2
* FMX white beamstop
FMXWBS 5 +wbstf_zd +wbstf_yt +wbstf_xo -wbstf_zu -wbstf_yb -wbstf_xi
* FMX Brem Stop
BRMSFMX 5 +brmsfmx -brmsf_ap
* FMX Brem stop APERTURE
BRMSTPA2 5 +brmsf_ap
* FMX HFM Mirror1
HFM1 5 +hfm1
* AMX photon Shutter APERTURE
SHUTERAP 5 +psh_ap
* AMX photon Shutter
SHUTTER 5 +psh -psh_ap
* FMX photon Shutter APERTURE
PSHF MXAP 5+pshf_ap
* FMX photon Shutter
PSHF MX 5 +pshfmx -pshf_ap
* Guillotine
GILOTINE 5 +giotn -giotn_ap -giotnf_a
* Guillotine APERTURE AMX
GILOAP 5 +giotn_ap
* Guillotine APERTURE

GILOAPF  5 +giotnfa

* Storage ring outer shielding

SOW_SHLD  5 + rwxxA_o + rwxxA_s + rfxxA_t - rwxxA_i - swxxA_i - flxxA_t
         | + swxxA_o + swxxA_s + rfxxA_t - rwxxA_o - swxxA_i - flxxA_t
         | + rwxxA_s + swxxA_s + flxxA_t - rwxxA_i - swxxA_i - flxxA_b

ARF_SHD  5 + bswxxA_o + bbwxxA_o + brfxxA_t - rwxxA_o - swxxA_o - brfxxA_b

ENC_A  5 + bswxxA_i + bbwxxA_i + brfxxA_b - rwxxA_o - swxxA_o - flxxA_t - brmcol - dcma1 - dcma2 - psh - brms
        - sgb01 - giotn - fm_afl - fm_af2
        - (+wbsta_zd + wbsta_yt + wbsta_xo - wbsta_zu - wbsta_yb - wbsta_xi )
        - (+wbstf_zd + wbstf_yt + wbstf_xo - wbstf_zu - wbstf_yb - wbstf_xi )
        - tdml - dcmf1 - dcmf2 - brmsfmx - hfm1 - pshfmx - sgb3
        - s1fmx - s2fmx - brmcol2 - s1bf - s2bf - s1ba - s2ba - ppsmfmx

ASW_SHD  5 + bswxxA_o + bbwxxA_i + brfxxA_b - rwxxA_o - flxxA_t - bswxxA_i

ABW_SHD  5 + bswxxA_o + bbwxxA_o + brfxxA_b - swxxA_o - flxxA_t - bbwxxA_i - blp_o - blpf_o

* Transport beampipe vacuum - AMX beam
tbp_va  5 + bfwwxB_o + blp_i - bbwxxA_i

* Transport beampipe shell - AMX beam
tbp_ss  5 + bfwwxB_o + blp_o - bbwxxA_i - blp_i

* Transport beampipe shielding - AMX beam
tbp_sh  5 + bfwwxB_o + blp_shd - bbwxxA_o - blp_o

* Transport beampipe vacuum - FMX beam
tbpf_va  5 + bfwwxB_o + blp_i - bbwxxA_i

* Transport beampipe shell - FMX beam
tbpf_ss  5 + bfwwxB_o + blp_o - blp_i - bbwxxA_i

* Transport beampipe shielding - AFX beam
tbpf_sh  5 + bfwwxB_o + blp_shd - bbwxxA_o - blpf_o

END

GEOEND

MATERIAL  2.35   26.    CONCRETE

COMPOUND -0.01  HYDROGEN  -0.54  OXYGEN  -0.02  SODIUM

COMPOUND -0.04  ALUMINUM  -0.34  SILICON  -0.05  CALCIUM

* ..+...1...+...2...+...3...+...4...+...5...+...6...+...7...

ASSIGNMA  BLCKHOLE    BLKBODY

ASSIGNMA  AIR        AIR

ASSIGNMA  VACUUM     ENC_A
ASSIGNMA  CONCRETE  SOW_SHLD
ASSIGNMA  LEAD  ARF_SHD
ASSIGNMA  LEAD  ASW_SHD
ASSIGNMA  LEAD  ABW_SHD
ASSIGNMA  LEAD  BRMCOL
ASSIGNMA  VACUUM  BRMCOLAP
ASSIGNMA  VACUUM  BRMCOLAF
*ASSIGNMA  AIR    CUTARG
ASSIGNMA  COPPER  S1BF
ASSIGNMA  VACUUM  S1BFAP
ASSIGNMA  COPPER  S2BF
ASSIGNMA  VACUUM  S2BFAP
ASSIGNMA  COPPER  S1BA
ASSIGNMA  VACUUM  S1BAAP
ASSIGNMA  COPPER  S2BA
ASSIGNMA  VACUUM  S2BAAP
ASSIGNMA  LEAD  BRMCOL2
ASSIGNMA  VACUUM  BRMCOL2A
ASSIGNMA  SILICON  TDM1
ASSIGNMA  SILICON  HFM1
ASSIGNMA  SILICON  DCMA1
ASSIGNMA  SILICON  DCMA2
ASSIGNMA  SILICON  DCMF1
ASSIGNMA  SILICON  DCMF2
ASSIGNMA  VACUUM  SC01AP
ASSIGNMA  COPPER  AMXWBS
ASSIGNMA  COPPER  FMXWBS
ASSIGNMA  COPPER  PPSMFMX
ASSIGNMA  VACUUM  PPSMAP
ASSIGNMA  COPPER  S1FMX
ASSIGNMA  VACUUM  S1FMXAP
ASSIGNMA  COPPER  S2FMX
ASSIGNMA  VACUUM  S2FMXAP
*ASSIGNMA  AIR    SC02
*ASSIGNMA  VACUUM  SC02AP
ASSIGNMA  LEAD  SGB02
ASSIGNMA  VACUUM  SGB2_APA  
ASSIGNMA  VACUUM  SGB2_APF  
*ASSIGNMA  LEAD  SGB3PF  
*ASSIGNMA  VACUUM  SGB3AP  
ASSIGNMA  VACUUM  BRMSTPA2  
ASSIGNMA  TUNGSTEN  BRMSTP1  
ASSIGNMA  VACUUM  BRMSTPA2  
ASSIGNMA  TUNGSTEN  BRMSFMX  
ASSIGNMA  TUNGSTEN  SHUTTER  
ASSIGNMA  VACUUM  SHUTERAP  
ASSIGNMA  TUNGSTEN  PSHFMX  
ASSIGNMA  VACUUM  PSHFMXAP  
ASSIGNMA  VACUUM  GILMA  
ASSIGNMA  VACUUM  GILMAPF  
ASSIGNMA  LEAD  GILOTINE  
ASSIGNMA  COPPER  FM_XXA  
ASSIGNMA  COPPER  FM_XXF  
ASSIGNMA  VACUUM  FMA_XXF  
ASSIGNMA  VACUUM  FMA_XXF  
ASSIGNMA  VACUUM  tbp_va  
ASSIGNMA  IRON  tbp_ss  
ASSIGNMA  LEAD  tbp_sh  
ASSIGNMA  VACUUM  tbpf_va  
ASSIGNMA  IRON  tbpf_ss  
ASSIGNMA  LEAD  tbpf_sh  
ASSIGNMA  LEAD  SC01  
PHOTONUC  1.  
HYDROGEN  @LASTMAT  
LAM-BIAS  0.0  0.02  COPPER  PHOTON  
LAM-BIAS  0.0  0.02  LEAD  PHOTON  
LAM-BIAS  0.0  0.02  IRON  PHOTON  
LAM-BIAS  0.0  0.02  TUNGSTEN  PHOTON  
LAM-BIAS  0.0  0.02  CONCRETE  PHOTON  
LAM-BIAS  0.0  0.02  SILICON  PHOTON  
USRBIN  10.  DOSE-EQ  -30.  200.0  200.0  2000.0FOE_T  
USRBIN  -200.0  -100.0  0.0  40.  60.  200. &  
AUXSCORE  USRBIN  ALL-PART  FOE_T  AMB74
| USRBIN | DOSE-EQ | -30. | 200.0 | 200.0 | 2000.0FOE_P |
|        |         |      |       |       |            |
| USRBIN |         | -200.0 | -100.0 | 0.0 | 40. | 60. | 200. & |
| AUXSCORE | USRBIN | PHOTON | FOE_P | AMB74 |
| USRBIN | DOSE-EQ | -30. | 200.0 | 200.0 | 2000.0FOE_N |
| USRBIN |         | -200.0 | -100.0 | 0.0 | 40. | 60. | 200. & |
| AUXSCORE | USRBIN | NEUTRON | FOE_N | AMB74 |
| USRBIN | DOSE-EQ | -31. | 150. | 211.0 | 2000.0RF_T |
| USRBIN |         | -100. | 201.0 | 0. | 250. | 20. | 400. & |
| AUXSCORE | USRBIN | ALL-PART | RF_T | AMB74 |
| USRBIN | DOSE-EQ | -31. | 150. | 211.0 | 2000.0RF_N |
| USRBIN |         | -100. | 201.0 | 0. | 250. | 20. | 400. & |
| AUXSCORE | USRBIN | NEUTRON | RF_N | AMB74 |
| USRBIN | DOSE-EQ | -31. | 168.8 | 50. | 2000.0SW_T |
| USRBIN |         | -150.0 | -150.0 | 1890.0 | 60.0 | 60.0 | 50.0 & |
| AUXSCORE | USRBIN | ALL-PART | SW_T | AMB74 |
| USRBIN | DOSE-EQ | -32. | 150.0 | 150.0 | 1940.0BW_T |
| USRBIN |         | -150.0 | -150.0 | 1890.0 | 60.0 | 60.0 | 50.0 & |
| AUXSCORE | USRBIN | NEUTRON | BW_N | AMB74 |
| USRBIN | DOSE-EQ | -32. | 150.0 | 150.0 | 1940.0BW_N |
| USRBIN |         | -150.0 | -150.0 | 1890.0 | 60.0 | 60.0 | 50.0 & |
| AUXSCORE | USRBIN | NEUTRON | BW_P | AMB74 |
| USRBIN | DOSE-EQ | -33. | 100. | 100. | 2000.0MoreT |
| USRBIN |         | -100. | -100. | 0.0 | 100. | 100. | 1000.0 & |
| AUXSCORE | USRBIN | ALL-PART | MoreT | AMB74 |
| USRBIN | DOSE-EQ | -33. | 100. | 100. | 2000.0MoreN |
| USRBIN |         | -100. | -100. | 0.0 | 100. | 100. | 1000. & |
| AUXSCORE | USRBIN | NEUTRON | MoreN | AMB74 |
| USRBIN | DOSE-EQ | -33. | 100. | 100. | 2000.0MoreP |
| USRBIN |         | -100. | -100. | 0.0 | 100. | 100. | 1000. & |
| AUXSCORE | USRBIN | PHOTON | MoreP | AMB74 |
USRBIN           10.   DOSE-EQ      -35.      20.0       20.    2400.0 TP_T
USRBIN          -20.       -4.    1900.0       40.       24.     500.0 &
AUXSCORE      USRBIN ALL-PART      TP_T          AMB74
USRBIN           10.   DOSE-EQ      -35.      20.0       20.    2400.0 TP_N
USRBIN          -20.       -4.    1900.0       40.       24.     500.0 &
AUXSCORE      USRBIN NEUTRON      TP_N          AMB74
USRBIN           10.   DOSE-EQ      -35.      20.0       20.    2400.0 TP_P
USRBIN          -20.       -4.    1900.0       40.       24.     500.0 &
AUXSCORE      USRBIN PHOTON      TP_P          AMB74

#define bl 4500
* Distance of DS ratchet wall from Straight Center
#define zro 2546.821
* Distance of Front End (FE) centerline from Straight Centerline
#define xro 0.318
#define sgb0 0.480
#define slbfap0 -2.465
#define slbaapOS 3.054
!@what.1=1.144*inch
#define sgb01xo 2.90576
#define sgb01yo 3.0
#define sgb02OS -3.7
#define wbsOS 0.0
#define wbsta xm 1.2521*inch
#define brsaOS 3.0
* PPS mask offset
#define ppsmos -3.5062
#define brmcol2x -3.518
#define s1fOS -3.59
#define s2fOS -3.63
* SGB3 FMX aperture offset
#define sgb3xos -6.682
#define hfm1OS -6.889
#define pshOS 3.0
#define pshOSx 23.327
#define pshOSfmx -7.867
#define gioOS 0.0
#define dcmOS 0.0
* Beam position and direction
!@what.1=C(BEAMPOS,0,1)
!@what.2=C(BEAMPOS,0,2)
!@what.3=C(BEAMPOS,0,3)
!@what.7=bl*C(BEAMPOS,0,4)
!@what.8=bl*C(BEAMPOS,0,5)
!@what.9=bl*sqrt(1.0-C(BEAMPOS,0,4)**2-C(BEAMPOS,0,5)**2)
arrow -4. 0.0 1273. 500. 220.beam
arrow -4.50585 0.04499.99774 &
* Beam position and direction
*!arrow 1.5 0.0 590.0 500. 220.beam
*!arrow 0.3 0.0 100.0 &
* Beam position and direction
*!arrow -140.0 1.0778 -530.0 500. 220.beam
*!arrow 0.0 0.0 4500.0 &
!@what.2=b(brmcolap,2)
!@what.3=b(brmcolap,5)
!@what.7=b(brms,2)-b(brmcolap,2)-4.613
!@what.9=b(brms_ap,5)-b(brmcolap,5)
*!arrow 0.0 3.536 95.059 0.0 0.0 0.0UMaxRayH
*!arrow .236 0.0 246.3 &
!@what.2=b(brmcolap,4)
!@what.3=b(brmcolap,5)
!@what.8=b(brms_ap,3)-b(brmcolap,4)-2.828
!@what.9=b(brms_ap,5)-b(brmcolap,5)
arrow 0.0 .6 95.059 0.0 0.0 0.0UMaxRayV
arrow 0.0 -.928 246.3 &
* Set the random number seed
RANDOMIZ 1.0
* Set the number of primary histories to be simulated in the run
START 200000.
STOP